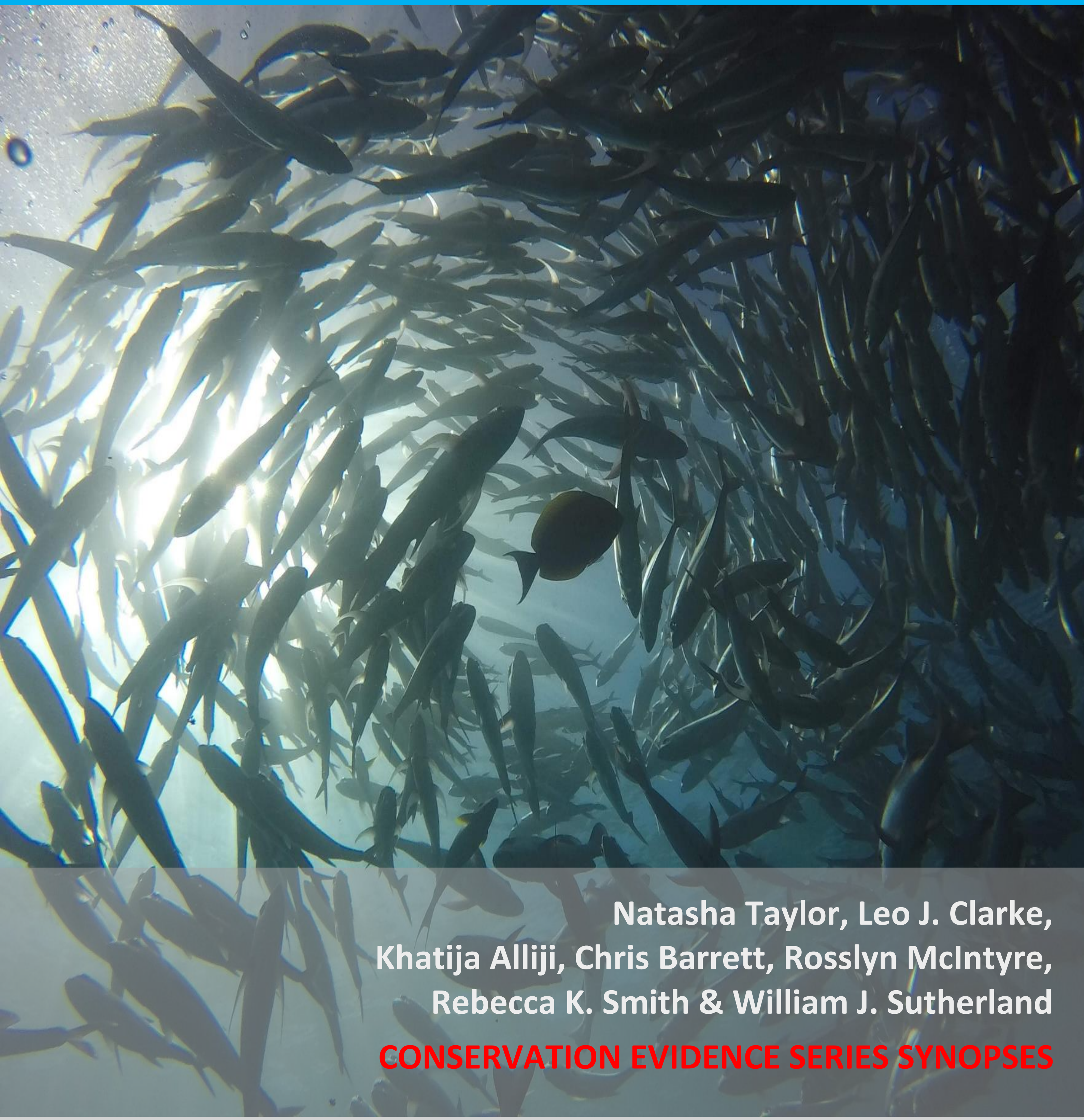
Marine Fish Conservation

Global evidence for the effects of selected interventions



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CONSERVATION EVIDENCE SERIES SYNOPSES

Marine Fish Conservation

Global evidence for the effects of selected interventions

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Conservation Evidence Series Synopses

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Cover image: Circling fish in the waters of the Halmahera Sea (Pacific Ocean) off the Raja Ampat Islands, Indonesia, by Leslie Burkhalter.

Digital material and resources associated with this synopsis are available at https://www.conservationevidence.com/

Contents

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1. About this book

1.1 The Conservation Evidence project

The Conservation Evidence project is constituted of four main parts:

1. The **synopses** of the evidence captured for the conservation of particular species groups or habitats (such as this synopsis). Synopses bring together the evidence for each possible intervention that was identified. They are freely available online and, in some cases, available to purchase in printed book form.

2. An ever-expanding **database of summaries** of previously published scientific papers, reports, reviews or systematic reviews that document the effects of interventions. This resource comprises over 6,616 pieces of evidence, all available in a searchable database on the website www.conservationevidence.com.

3. ***What Works in Conservation,*** which is an assessment of the effectiveness of interventions by expert panels, based on the collated evidence for each intervention for each species group or habitat covered by the synopses. This is available as part of the searchable database and is published as an updated book edition each year (https://www.conservationevidence.com/content/page/79).

4. An online **open access journal, *Conservation Evidence*** that publishes new pieces of research on the effects of conservation management interventions. All the papers published are written by, or in conjunction with, those who carried out the conservation work and include some monitoring of its effects (https://www.conservationevidence.com/collection/view).

You can learn more about the Conservation Evidence project and the methods behind it in Sutherland *et al.* (2019).

1.2 The purpose of Conservation Evidence synopses

Conservation Evidence synopses **do**	Conservation Evidence synopses **do not**
Bring together scientific evidence captured by the Conservation Evidence project (over 6,616 studies so far) on the effects of interventions to conserve and restore biodiversity	Include evidence on the basic ecology of species or habitats, or threats to them
List all realistic interventions for the species group or habitat in question, regardless of how much evidence for their effects is available	Make any attempt to weight or prioritize interventions according to their importance or the size of their effects
Describe each piece of evidence, including methods, as clearly as possible, allowing readers to assess the quality of evidence	Weight or numerically evaluate the evidence according to its quality
Work in partnership with conservation practitioners, policymakers, and scientists to develop the list of interventions and ensure we have covered the most important literature	Provide recommendations for conservation problems, but instead provide scientific information to help with decision-making

1.3 Who is this synopsis for?

If you are reading this, we hope you are someone who does, or wants to, make decisions about how best to support, manage, and conserve the marine environment and its biodiversity. You might be a marine conservationist in the public or private sector, a campaigner, a marine advisor or consultant, a policymaker, a researcher, someone taking action to protect the marine environment, or a concerned citizen. This synopsis summarizes scientific evidence relevant to your conservation objectives and the actions you could take to achieve them.

We do not aim to make your decisions for you, but to support your decision-making by telling you what evidence there is (or isn't) about the effects that your or others' planned actions could have. Here, by "evidence", we mean any scientific studies found during our systematic searches (see below section 1.6) that quantitatively report the effects of conservation actions (interventions).

When decisions have to be made with particularly important or irreversible consequences, we recommend carrying out a systematic review, as the latter is likely to be more comprehensive than the summary of evidence presented here. Guidance on how to carry out systematic reviews can be found from the Centre for Evidence-Based Conservation at the Bangor University (www.cebc.bangor.ac.uk).

1.4 Background

There is increasing need for policy makers and managers to assess the impact of human pressures on the marine environment and to recommend and implement measures that restrain, reduce or eliminate these pressures. These activities are undertaken by multidisciplinary organisations, including international, government and regulatory agencies, devolved governments, local authorities, non-governmental organisations and science advisors. When assessing potential pressures on the marine environment, each of these bodies employs staff to scrutinise the available scientific evidence-base for guidance on best practice to reduce impacts.

Reviewing the evidence to inform marine management decisions is a time-consuming and costly exercise. In general, the assessment of the evidence-base is approached on a case by case basis. It is recognised that many stakeholders, intergovernmental bodies and advisory groups strive for a standardised approach to data collection with respect to, for example, terminology and methods for assessing fish populations and, that these standards differ with the amount of data available for a given fish resource. However, often, different stakeholders independently conduct evidence reviews relative to their specific application or enquiry. This approach is counter to the philosophy of 'produce once and use many times over' and is a highly inefficient use of resources. This means that evidence is assessed and interpreted many times over, but with the risk that evidence included in different reviews, and the way that it is assessed, will be inconsistent, draws on different expert opinion, and replicates effort that has been spent on previous reviews. This lack of consistency can lead to informal reviews that vary in their quality and potential bias due to differences in objectivity and comprehensiveness (see Woodcock et al. 2017). The inefficiency in this process is obvious, but may result in a lack of repeatability and accuracy if methods are not clearly explained; one review may draw different conclusions based on similar evidence, and has the potential to lead to different management recommendations from different agencies or stakeholders. One serious consequence of divergent interpretation is that decisions and the evidence assessment process are then more open to challenge, which may require further investigation to resolve conflicts, slowing down the process and using more resources.

Fishing is one of the most widespread sources of human disturbance in marine and aquatic environments, and many ecosystems and fish populations have been dramatically altered as a result of fishing activities. Effective management is complicated by conflicting interests of multiple stakeholders and there is an increasing need for evidence-based management and conservation of fish populations and communities (Cooke et al. 2017). While a large amount of evidence exists, it is often not collated and summarized in an easily accessible format. This project has summarized and evaluated the available global scientific evidence on the effectiveness of conservation interventions in marine and transitional aquatic environments and incorporated this information into an online free to use searchable database (www.ConservationEvidence.com). In doing so, the output of our project will contribute to the maintenance and enhancement of the quality of the marine environment.

1.5 Scope of the review

1.5.1 Review subject

This synopsis covered published evidence for the effectiveness of global conservation interventions, and management interventions, aimed at conserving, but also restoring and promoting, marine fish species and communities. This subject has not yet been covered using subject-wide evidence synthesis. This is defined as a systematic method of evidence synthesis that covers entire subjects at once, including all closed review topics within that subject at a fine scale and analysing results through study summary and expert assessment, or through meta-analysis; the term can also refer to any product arising from this process (Sutherland *et al*. 2019). The topic was therefore a priority for the discipline-wide Conservation Evidence database.

The present synthesis focussed on evidence for the effects of *selected* conservation interventions for wild marine fish (i.e. not in captivity). We included evidence for actions from a prioritized list of categories on the advice of the advisory board, i.e. those that fall under the International Union for the Conservation of Nature (IUCN) direct threat category 'Biological resource use' (http://www.iucnredlist.org/technical-documents/classification-schemes/threatsclassification-scheme). As a result, for this synthesis, conservation interventions included fisheries management measures that aim to conserve fish stocks and ameliorate the deleterious effects of fishing activity. The full list of categories and actions not covered within this synthesis are provided in Appendix 1. Note: Evidence for the interventions listed under 'Catch, Effort and Capacity Reduction' has been compiled and is currently being summarised. This section will be updated as soon as that is completed.

This global synthesis collates evidence for the effects of selected conservation actions for all wild marine fish species within all marine ecosystems and habitat types. We did not include evidence from the substantial literature on husbandry of commercially reared cultured marine fish or those kept in zoos.
Evidence for the effectiveness of interventions targeting conservation of diadromous species (those that spend a part of their life cycle in freshwater habitats and part in marine habitats) have been summarized only for studies that were carried out in marine and estuarine aquatic habitats. Interventions relating to the conservation of these species carried out in freshwater habitats will be collated separately to be retained for any future synopsis covering this theme.

The output of the project is an authoritative, freely accessible evidence-base that will support marine management objectives and help to achieve conservation outcomes and more sustainable use of marine biological resources.

1.5.2 Advisory board

An advisory board made up of 19 international conservationists and academics with expertise in fisheries and marine fish conservation was formed. These experts provided input into the evidence synthesis at three key stages: a) reviewing the protocol including identifying key sources of evidence, b) developing a comprehensive list of conservation interventions for review and c) reviewing the draft evidence synthesis. The advisory board is listed above.

1.5.3 Creating the list of interventions

At the start of the project, a comprehensive list of interventions was developed by scanning the literature and in partnership with the advisory board. The list was also checked by Conservation Evidence to ensure that it followed the standard structure (described below). The aim was to include all actions that have been carried out or advised to support populations or communities of wild marine fish, whether evidence for the effectiveness of an action is available or not. During the synthesis process further interventions were discovered and integrated into the synopsis structure.

The list of interventions was organized into categories based on the IUCN classifications of direct threats (http://www.iucnredlist.org/technical-documents/classification-schemes/threatsclassification-scheme) and conservation actions (http://www.iucnredlist.org/technicaldocuments/classification-schemes/conservation-actions-classification-scheme-ver2).

In total, we found 93 conservation and/or management interventions that could be carried out to conserve marine fish populations from our *selected* categories (see explanation note in 1.5.1 above). We found evidence for the effects on marine fish populations of 66 of these interventions. The evidence was reported as 544 summaries from 424 relevant publications found during our searches (see Methods below).

Note: Evidence for the interventions listed under 'Catch, Effort and Capacity Reduction' has been compiled and is currently being summarised. This section will be updated as soon as that is completed.

1.6 Methods

1.6.1 Literature searches

Literature was obtained from the Conservation Evidence discipline-wide literature database, and from searches of additional subject specific literature sources (see Appendices 2 & 3). The Conservation Evidence discipline-wide literature database is compiled using systematic searches of journals; relevant publications that describe studies of conservation interventions for all species groups and habitats are saved from each journal and are added to the database. The final list of evidence sources searched for this synopsis is published in this synopsis document – see Appendix 2, and the full list of journals and report series searched is published online (https://www.conservationevidence.com/journalsearcher/synopsis).

a) Global evidence

Evidence from all around the world was included.

b) Languages included

Only English language journals were included in this synopsis. A study on the topic of language barriers in global science indicates that approximately 35% of conservation studies may be in non-English languages (Amano et al. 2016). While searching only English language journals may therefore potentially introduce some bias to the review process, project resources and time constraints determined the number of journals that could be searched within the project timeframe.

c) Journals searched

i) From Conservation Evidence discipline-wide literature database

All of the journals (and years) listed in Appendix 2b were searched prior to or during the completion of this project by authors of other synopses, and relevant papers added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the journals most relevant to this synopsis. Others are less likely to include papers relevant to this synopsis, but if they did, those papers were summarized.

ii) Update searches

No additional searches of any of the journals listed in Appendix 2b were undertaken as part of this synopsis, as we prioritised searches to specialist journals that were more likely to yield studies that focus on marine fisheries management and conservation.

iii) New searches

Targeted searches of journals most relevant to the conservation of marine fish populations, listed below (and in Appendix 2a), were undertaken. These journals were identified through expert judgement by the project researchers and the advisory board and ranked in order of relevance, to prioritise searches that were considered likely to yield higher numbers of relevant studies. These journals were not searched from the first year of publication; rather searches were done working backwards from the end of 2018, either to the earliest published volume where possible, or for 30 years for long-running journals.

- Fish and Fisheries
- Fisheries
- Fisheries Management & Ecology
- Fisheries Oceanography
- Fisheries Research
- ICES Journal of Marine Science
- Journal of Coastal Research

d) Reports from specialist websites searched

i) From Conservation Evidence discipline-wide literature database

All of the report series (and years) below have already been systematically searched for the Conservation Evidence project. An asterisk indicates the report series most relevant to this synopsis. Others were less likely to have included reports relevant to this synopsis, but if they did, they were summarized.

• Amphibian Survival Alliance	1994-2012	Vol 9 - Vol 104
• British Trust for Ornithology	1981-2016	Report 1-687
• IUCN Invasive Species Specialist Group	1995-2013	Vol 1 - Vol 33
• Scottish Natural Heritage*	2004-2015	Reports 1-945

ii) Update searches

Updates to reports already searched as part of the wider Conservation Evidence project were not undertaken for this synopsis.

iii) New searches

No new report searches were undertaken for this synopsis due to time constraints.

e) Other literature searches

i) Conservation Evidence online database

The online database www.conservationevidence.com was searched for relevant publications that had already been summarized. If such summaries existed, they were extracted and added to this synopsis.

ii) Systematic and non-systematic reviews

Where a systematic review was found for an intervention, it was summarized. However, each relevant study included in the systematic review was not summarized due to time constraints. Where a non-systematic review (or editorial, synthesis, preface, introduction etc.) was found for an intervention, the review itself was not summarized, unless the review also provided new/collective data. Relevant publications cited in these non-systematic reviews were not summarized at this stage.

f) Supplementary literature identified by advisory board or relevant stakeholders

Additional journal or specialist website searches, and relevant papers or reports suggested by the advisory board or relevant stakeholders were also included, where time permitted.

g) Search record database

A database was created of all relevant publications found during searches. Reasons for exclusion were recorded for all studies included during screening but that were not summarized for the synopsis.

1.6.2 Publication screening and inclusion criteria

A summary of the total number of evidence sources and papers/reports screened is presented in the diagram in Appendix 3. The initial screening process was at the title and abstract level. If selected following this initial screening, a second one at the full-text level was undertaken, to validate whether the study indeed fitted the Conservation Evidence inclusion criteria (described below).

a) Screening

To ensure consistency/accuracy when screening publications for inclusion in the literature database, an initial test using the Conservation Evidence inclusion criteria (provided below) and a consistent set of references was carried out by the authors, compared with the decisions of the experienced core Conservation Evidence team. Results were analysed using Cohen's Kappa test (Cohen 1960). Where initial results did not show 'substantial' (K=0.61–0.8) or 'almost perfect' agreement (K= 0.81–1.0), authors were given further training. A second Kappa test was used to assess the consistency/accuracy of article screening for the first two years of the first journal searched by each author. Again, where results did not show 'substantial' (K=0.61–0.8) or 'almost perfect' agreement (K= 0.81–1.0), authors received further training and were tested again before carrying out further searches.

Authors of other synopses who have searched journals and added relevant publications to the Conservation Evidence literature database since 2018, and all other searchers since 2017 have undertaken the initial paper inclusion test described above; searchers prior to that have not. Kappa tests of the first two years searched has been carried out for all new searchers who have contributed to the Conservation Evidence literature database since July 2018.

We acknowledge that the literature search and screening method used by Conservation Evidence, as with any method, results in gaps in the evidence. The Conservation Evidence literature database currently includes relevant papers from over 270 English language journals as well as over 150 non-English journals. Additional journals are frequently added to those searched, and years searched are often updated. It is possible that searchers will have missed relevant papers from those journals searched. Potential publication bias is not taken into account, and it is likely that additional biases will result from the evidence that is available, for example there are often geographic biases in study locations.

b) Inclusion criteria

The following Conservation Evidence inclusion criteria were used.

Criteria A: Conservation Evidence includes studies that measure the effect of an action that might be done to conserve biodiversity

1. Does this study measure the effect of an action that is or was under the control of humans, on wild taxa (including captives), habitats, or invasive/problem taxa? If yes, go to 3. If no, go to 2.
2. Does this study measure the effect of an action that is or was under the control of humans, on human behaviour that is relevant to conserving biodiversity? If yes, go to Criteria B. If no, exclude.
3. Could the action be put in place by a conservationist/decision maker to protect, manage, restore or reduce impacts of threats to wild taxa or habitats, or control or

mitigate the impact of the invasive/problem taxon on wild taxa or habitats? If yes, include. If no, exclude.

Explanation:
1.a. Study must have a measured outcome on wild taxa, habitats or invasive species: excludes studies on domestic/agricultural species, theoretical modelling or opinion pieces. See Criteria B for actions that have a measured outcome on human behaviour only.

1.b. Action must be carried out by people: excludes impacts from natural processes (e.g. tree falls, natural fires), impacts from background variation (e.g. sediment type, submerged vegetation, climate change), correlations with habitat types, where there is no test of a specific action by humans, or pure ecology (e.g. movement, distribution of species).

2. Study must test an action that could be put in place for conservation. This excludes assessing impacts of threats (actions which remove threats would be included). The test may involve comparisons between sites/factors not originally put in place or modified for invertebrate conservation, but which could be (e.g. modified fishing net vs unmodified fishing net, fished sites vs sites where fishing stopped – where the net modification/fishing cessation is as you would do for conservation, even if that was not the original intention in the study).

If the title and/or abstract are suggestive of fulfilling our criteria, but there is not sufficient information to judge whether the action was under human control, whether the action could be applied by a conservationist/decision maker or whether there are data quantifying the outcome, then include. If the article has no abstract, but the title is suggestive, then a study will be included.

We sort articles into folders by which taxon/habitat they have an outcome on. If the title/abstract does not specify which species/taxa/habitats are impacted, then the full article will be scanned and then assigned to folders accordingly.

The outcome for wild taxa/habitats can be negative, neutral or positive, does not have to be statistically significant but must be quantified (if hard to judge from abstract, then include). It could be any outcome that has implications for the health of individuals, populations, species, communities or habitats, including, but not limited to the following:

- Individual health, condition or behaviour, including in captivity: e.g., growth, size, weight, stress, disease levels or immune function, movement, use of natural/artificial habitat/structure, range, or predatory or nuisance behaviour that could lead to retaliatory action by humans.
- Breeding: egg/larvae/sperm production, mating success, birth rate, clutch size, , 'overall recruitment'
- Genetics: genetic diversity, genetic suitability (e.g. adaptation to local conditions.)
- Life history: age/size at maturity, survival, mortality

- Population measures: number, abundance, density, presence/absence, biomass, movement, cover, age-structure, species distributions (only in response to a human action), disease prevalence, sex ratio
- Community/habitat measures: species richness, diversity measures (including trait/functional diversity), community composition, community structure (e.g. trophic structure), area covered, physical habitat structure (e.g. rugosity, height, basal area)

Actions within the scope of Conservation Evidence include:

- Clear management actions: creation of artificial structures, planting submerged vegetation, controlling or eradicating invasive species, creating marine protected areas, creating or restoring habitats.
- International, national, or local policies: creation of marine protected area, bylaws, local voluntary restrictions.
- Reintroductions or management of wild species in captivity
- Actions that reduce human-wildlife conflict
- Actions that change human behaviour, resulting in an impact on wild taxa or habitats

See https://www.conservationevidence.com/data/index for more examples of actions.

Note on study types:
Literature reviews, systematic reviews, meta-analyses or short notes that review studies that fulfil these criteria are included.

Theoretical modelling studies were excluded, as no intervention has been taken. However, studies that use models to analyse real-world data, or compare models to real-world situations are included (if they otherwise fulfil these criteria).

Criteria B: Conservation Evidence includes studies that measure the effect of an action that might be done to change human behaviour for the benefit of biodiversity

1. Does this study measure the effect of an action that is or was under human control on human behaviour (actual or intentional) which is likely to protect, manage, restore or reduce threats to wild taxa or habitats? If yes, go to 2. If no, exclude.
2. Could the action be put in place by a conservationist, manager or decision maker to change human behaviour? If yes, include. If no, exclude.

Explanation:

1.a. Study must have a measured outcome on <u>actual or intentional human behaviour</u> including self-reported behaviours: excludes outcomes on human psychology (tolerance, knowledge, awareness, attitude, perceptions or beliefs)

1.b. Change in human behaviour must be linked to outcomes for wild taxa and habitats, excludes changes in behaviour linked to outcomes for human benefit, even if these occurred under a conservation program (e.g. we would exclude a study demonstrating increased school attendance in villages under a community-based conservation program)

1.c. Action must be under human control: excludes impacts from climatic or other natural events.

2. Study must test an action that could be put in place for conservation: excludes studies with no action e.g. correlating human personality traits with likelihood of conservation-related behaviours.

The human behaviour outcome of the study can be negative, neutral or positive, does not have to be statistically significant but must be quantified (if hard to judge from abstract, then include). It could be any behaviour that is likely to have an outcome on wild taxa and habitats (including mitigating the impact of invasive/problem taxon on wild taxa or habitats). Actions include, but are not limited to the following:

- Change in adverse behaviours (which directly threaten biodiversity): e.g. unsustainable fishing (industrial, artisanal, recreational), urban encroachment, creating noise, entering sensitive areas, polluting or dumping waste, clearing or habitat destruction, introducing invasive species
- Change in positive behaviours: e.g. uptake of alternative/sustainable livelihoods, number of households adopting sustainable practices, donations, donations
- Change in policy or conservation methods: e.g. placement of protected areas, protection of key habitats/species
- Change in consumer or market behaviour: e.g. purchasing, consuming, buying, willingness to pay, selling, illegal trading, advertising, consumer fraud
- Behavioural intentions to do with any of the above

Actions which are particularly likely to induce a human behaviour change include, but are not limited to the following:

- Enforcement: closed seasons, size limits, fishing gear restrictions, auditable/traceable reporting requirements, market inspections, increased number of rangers, patrols or frequency of patrols in, around or within protected areas, improved fencing/physical barriers, improved signage, improved equipment/technology used by guards, use of UAVs/drones for rapid response, DNA analysis, GPS tracking.
- Behaviour Change: promote alternative/sustainable livelihoods, payment for ecosystem services, ecotourism, poverty reduction, increased appreciation or knowledge, debunking misinformation, altering or re-enforcing local taboos, financial incentives.
- Governance: Protect or reward whistle-blowers, increase government transparency, ensure independence of judiciary, provide legal aid
- Market Regulation: trade bans, taxation, supply chain transparency laws

- Consumer Demand Reduction: Increase awareness or knowledge, fear appeals
- (negative association with undesirable product), benefit appeal (positive association with desirable behaviour), worldview framing, moral framing, employing decision defaults, providing decision support tools, simplifying advice to consumers, promoting desirable social norms, legislative prohibition.
- Sustainable Alternatives: Certification schemes, captive bred or artificial alternatives, sustainable alternatives.
- New policies for conservation/protection

We allocated studies to folders by their outcome. All studies under Criteria B go in the 'Human behaviour change' folder. They are additionally duplicated into a taxon/habitat folder if there is a specific intended final outcome of the behaviour change (if none mentioned, file only in Human behaviour change).

Relevant subject

Studies relevant to the synopsis subject included those focused on the conservation of wild, native marine fish and carried out in marine and estuarine habitats.

Relevant types of intervention

An intervention has to be one that could be put in place by a fisheries manager, conservationist or policy maker to protect, manage, restore or reduce the impacts of threats to wild native marine fish, or control or mitigate the impact of an invasive/problem taxon on marine fish. Alternatively, interventions may aim to change human behaviour (actual or intentional), which is likely to protect, manage, restore or reduce threats to marine fish populations. See inclusion criteria above for further details.

If the following two criteria were met, a combined intervention was created within the synopsis, rather than repeating evidence under all the separate interventions: a) there were five or more publications that used the same well-defined combination of interventions, with very clear description of what they were, without separating the effects of each individual intervention, and b) the combined set of interventions is a commonly used conservation strategy.

Relevant types of comparator

To determine the effectiveness of interventions, studies must include a comparison, i.e. monitoring change over time (typically before and after the intervention was implemented), or for example comparing "treatment" sites where an intervention was undertaken or implemented, and "control" sites where not intervention took place but the threat occurred.

Alternatively, a study could compare one specific intervention (or implementation method) against another. For example, this could be comparing the abundance of a species before and after the closure of an area to fishing activities, or the species selectivity or unwanted catch reduction of two different mesh sizes used in fishing gear.

Exceptions, which may not have one of the suitable comparators listed above, but will still be included, are for example, studies comparing with "pristine" or "reference" sites, or studies where no comparator is realistic (e.g: the effectiveness of restocking or captive breeding programmes, or of eradicating or controlling introduced species).

Relevant types of outcome

Below we provide a list of anticipated metrics; others were included if reported within relevant studies.

- Community response
    - Community composition
    - Richness/diversity
- Population response
    - Abundance: number, density, presence/absence, biomass, age structure, sex ratio
    - Reproductive success: egg/larvae production, mating success, hatching rate, egg/larvae quality/condition, overall recruitment, age/size at maturity
    - Survival: survival, mortality
    - Condition: growth, size, weight, condition factors (condition indices), biochemical ratios, stress, disease levels, or immune function
- Behaviour:
    - Use by species of natural or artificial habitat, use of artificial structures or shelters
    - Species behaviour change: movement or migration patterns, changes in range
    - Human behaviour change
- Other
    - Reduction of unwanted catch ("bycatch")
    - Improved gear size-selectivity
    - Reduction of fishing effort
    - Commercial catch abundance/landings
    - Improved compliance/reduction of illegal fishing activity
    - Stock status

Relevant types of study design

The table below lists the study designs included. The strongest evidence comes from studies using the following experimental design: randomized, replicated, controlled trials with paired sites and before and after monitoring. For further information on study designs and their quality or strength, please see Christie *et al.* 2019.

Table 1. Study designs

Term	Meaning
Replicated	The intervention was repeated on more than one individual or site. In conservation and ecology, the number of replicates is much smaller than it would be for medical trials (when thousands of individuals are often tested). If the replicates are sites, pragmatism dictates that between five and ten replicates is a reasonable amount of replication, although more would be preferable. We provide the number of replicates wherever possible. Replicates should reflect the number of times an intervention has been independently carried out, from the perspective of the study subject. For example, 10 plots within a mown field might be independent replicates from the perspective of plants with limited dispersal, but not independent replicates for larger motile animals such as birds. In the case of translocations/release of captive bred animals, replicates should be sites, not individuals.
Randomized	The intervention was allocated randomly to individuals or sites. This means that the initial condition of those given the intervention is less likely to bias the outcome.
Paired sites	Sites are considered in pairs, within which one was treated with the intervention and the other was not. Pairs, or blocks, of sites are selected with similar environmental conditions, such as soil type or surrounding landscape. This approach aims to reduce environmental variation and make it easier to detect a true effect of the intervention.
Controlled*	Individuals or sites treated with the intervention are compared with control individuals or sites not treated with the intervention. (The treatment is usually allocated by the investigators (randomly or not), such that the treatment or control groups/sites could have received the treatment).
Before-and-after	Monitoring of effects was carried out before and after the intervention was imposed.
Site comparison*	A study that considers the effects of interventions by comparing sites that historically had different interventions (e.g. intervention vs no intervention) or levels of intervention. Unlike controlled studies, it is not clear how the interventions were allocated to sites (i.e. the investigators did not allocate the treatment to some of the sites).
Review	A conventional review of literature. Generally, these have not used an agreed search protocol or quantitative assessments of the evidence.

Systematic review	A systematic review follows structured, predefined methods to comprehensively collate and synthesise existing evidence. It must weight or evaluate studies, in some way, according to the strength of evidence they offer (e.g. sample size and rigour of design). Environmental systematic reviews are available at: www.environmentalevidence.org/index.htm
Study	If none of the above apply, for example a study measuring change over time in only one site and only after an intervention. Or a study measuring use of nest boxes at one site.

* Note that "controlled" is mutually exclusive from "site comparison". A comparison cannot be both controlled and a site comparison. However, one study might contain both controlled and site comparison aspects e.g. study of restored oyster reefs, compared to unrestored seabed plots (controlled) and natural, target oyster reefs (site comparison).

1.6.3 Study quality assessment & critical appraisal

We did not quantitatively assess the evidence from each publication or weigh it according to quality. However, to allow interpretation of the evidence, we clearly stated the size and design of each reported study.

We critically appraised each potentially relevant study and excluded those that did not provide data for a comparison to the treatment, did not statistically analyse the results (or if included this was stated in the summary paragraph), or had obvious errors in their design or analysis. A record of the reason for excluding any of the publications included during screening was kept within the synopsis database.

1.6.4 Data extraction

Data on the effectiveness of the relevant intervention (e.g. mean species abundance inside or outside a closed area; reduction in unwanted catch after modifications to fishing gear) were extracted from, and summarized for, publications that included the relevant subject, types of intervention, comparator and outcomes outlined above. A summary of the total number of evidence sources and papers/reports scanned, and the total number of publications included following data extraction is presented in Appendix 3.

In addition to ensuring consistency/accuracy when screening publications for inclusion in the discipline-wide literature database (see above), for a set of publications, relevant data was extracted by a member of the core Conservation Evidence team as well as the author to ensure agreement for inclusion in the synopsis. In addition, at the start of each month, authors swapped three summaries with another author to ensure that the correct type of data has been extracted and that the summary followed the Conservation Evidence standard format.

1.6.5 Evidence synthesis

a) Summary protocol

Each publication usually had just one paragraph for each intervention it tested, describing the study in (usually) no more than 200 words using plain English. To help with some of the terminology specific to the marine environment, and for which a suitable plain English equivalent does not exist, we provide a Glossary of terms (Appendix 4). Each summary used the following format:

A [TYPE OF STUDY] in [YEARS X-Y] in [HOW MANY SITES] in/of [HABITAT/SEABED TYPE] in [REGION, COUNTRY and WATER BODY] [REFERENCE] found that [INTERVENTION] [SUMMARY OF ALL KEY RESULTS] for [SPECIES/HABITAT TYPE]. [DETAILS OF KEY RESULTS, INCLUDING DATA]. In addition, [EXTRA RESULTS, IMPLEMENTATION OPTIONS, CONFLICTING RESULTS]. The [DETAILS OF EXPERIMENTAL DESIGN, INTERVENTION METHODS and KEY DETAILS OF SITE CONTEXT]. Data was collected in [DETAILS OF SAMPLING METHODS].

Type of study - use terms and order in Table 1.

Site context - for the sake of brevity, only nuances essential to the interpretation of the results are included. The reader is always encouraged to read the original source to get a full understanding of the study site (e.g. history of management, physical conditions).

For example:

A replicated, paired, site comparison study in 2002 of two coral reefs in the Philippine Sea, Philippines (1) found that prohibiting all fishing in a marine reserve resulted in higher density and biomass of species of fish taken by local fishers within the reserve compared to a fished area in, one of two cases. For species taken by fishers, density and biomass inside reserve one was higher (density: 68 fish/500 m^2; biomass: 89 kg) than outside (27 fish/500 m^2; 25 kg), but not significantly different inside and outside reserve two (density inside and outside: 41 fish/500 m^2; no biomass data provided). For fish species not subject to fishing, density was higher inside both reserves compared to outside, however statistical tests showed this was mainly due to habitat variation not protection status (reserve one: 146 fish/250 m^2 inside, 113/250 m^2 outside; reserve two: 93/250 m^2 inside, 32/250 m^2 outside). No-take reserves approximately 450 m long (protected for 20 years) and 650 m long (protected for 15 years) off two islands were each compared to fished areas approximately 500 m away. Fish were surveyed in November and December 2002. Divers surveyed fish at six (reserve one) and eight (reserve two) coral reef slope sites inside and outside each reserve. Counts were along 50 x 10 m transects for fish taken by fishers and 50 x 5 m transects for fish not fished. Transects were surveyed twice.

(1) Abesamis R.A., Russ G.A. & Alcala A.C. (2006) Gradients of abundance of fish across no-take marine reserve boundaries: Evidence from Philippine coral reefs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16, 349–371.

b) Terminology used to describe the evidence

Unless specifically stated otherwise, results reflect statistical tests performed on the data i.e. we only state that there was a difference if it was a statistically significant difference or state that there was no difference if it was not significant. Table 1 above defines the terms used to describe the study designs.

c) Dealing with multiple interventions within a publication

When separate results were provided for the effects of each of the different interventions tested, separate summaries have been written under each intervention heading. However, when several interventions were carried out at the same time and only the combined effect reported, the results were described with a similar paragraph under all relevant interventions. The first sentence makes it clear that there was a combination of interventions carried out, i.e. '.........(REF) found that [x intervention], along with [y] and [z interventions] resulted in [describe effects]'. Within the results section we also added a sentence such as: 'It is not clear whether these effects were a direct result of [x], [y] or [z] interventions', or 'The study does not distinguish between the effects of [x], and other interventions carried out at the same time: [y] and [z].'

d) Dealing with multiple publications reporting the same results

If two publications described results from the same intervention implemented in the same space and at the same time, we only included the most stringently peer-reviewed publication (i.e. if a study is published in an academic journal and in a report series, we would include the academic journal). If one included initial results (e.g. after year one) of another (e.g. after 1-3 years), we only included the publication covering the longest time span. If two publications described at least partially different results, we included both but made clear they were from the same project in the paragraph, e.g. 'A controlled study..... (Gallagher et al. 1999; same experimental set-up as Oasis et al. 2001).....'.

e) Taxonomy

The taxonomy used in each summary paragraph was not updated but followed that used in the original publication. Where possible, common names and Scientific names were both given the first time each species was mentioned within each summary.

f) Key messages

Each intervention has a set of concise, bulleted key messages at the top, which was written once all the identified literature had been summarized. These messages include information such as the number, design and location of included studies.

The first bullet point describes the total number of studies that tested the intervention and the locations of the studies, followed by key information on the relevant metrics presented under the headings and sub-headings shown below (with number of relevant studies in parentheses for each).

- **X studies** examined the effects of [INTERVENTION] on [TARGET POPULATION]. Y studies were in [LOCATION 1][1,2] and Z studies were in [LOCATION 2][3,4]. *Here, locations include body of water and country, ordered based on chronological order of studies rather than alphabetically, i.e. Mediterranean Sea[1], Baltic Sea[2] not Baltic Sea[2], Mediterranean Sea[1]. The distribution of studies amongst specific habitat types or species groups may also be added here if relevant to the intervention.*

COMMUNITY RESPONSE (x STUDIES)

- **Community composition (x studies):**
- **Richness/diversity (x studies):**

POPULATION RESPONSE (x STUDIES)

- **Abundance (x studies):**
- **Reproductive success (x studies):**
- **Survival (x studies):**
- **Condition (x studies):**

BEHAVIOUR (x STUDIES)

- **Use (x studies):**
- **Behaviour change (x studies):**
- **Human behaviour change (x studies):**

OTHER (x STUDIES) *(Included only for interventions/chapters where relevant)*

- **Reduction of unwanted catch (x studies):**
- **Improved size-selectivity of fishing gear (x studies):**
- **Reduction of fishing effort (x studies)**
- **Commercial catch abundance/landings (x studies):**
- **Improved compliance/reduction of illegal fishing activity (x studies)**
- **Stock status (x studies):**

1.6.6 Dissemination/communication of evidence synthesis

The information from this evidence synthesis is available in three ways:

- This synopsis pdf, downloadable from www.conservationevidence.com, which contains the study summaries, key messages and background information on each intervention.
- The searchable database at www.conservationevidence.com which contains all the summarized information from the synopsis, along with expert assessment scores.
- A chapter in *What Works in Conservation*, available as a pdf to download and a book from [https://www.conservationevidence.com/content/page/79], which contains the key messages from the synopsis as well as expert assessment scores on the effectiveness and certainty of the synopsis, with links to the online database.

1.7 How you can help to change conservation practice

If you know of evidence relating to the conservation of marine fish communities that is not included in this synopsis, we invite you to contact us, via our website www.conservationevidence.com. If you have new, unpublished evidence, you can submit a paper to the *Conservation Evidence* journal. We particularly welcome papers submitted by conservation practitioners.

1.8 References

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2. Threat: Biological resource use

Biological resource use can have significant impacts on marine fish: directly through species extraction by harvesting (reduced population of commercially targeted as well and non-targeted species - often referred to as "bycatch") and indirectly through impacts on the food chain (removal of predator and prey species and species that provide important functions within the habitat) and on the seabed from fishing gear (modification and destruction of seabed habitats)(Collie *et al*. 2000; Lambert *et al.* 2014; Sciberras *et al.* 2018; Watling & Norse 1998).

Please note that management interventions aimed at promoting the populations of commercial species to maximise the catches of retained fish (for consumption/animal trade etc.) are more closely related to harvest and fisheries management than conservation by itself (although they are interlinked). For that reason, in some sections (in particular '*Reduce Unwanted Catch and Discards, and Improve Survival of Returned or Escaped Fish*), only the outcomes for non-commercial species and the unwanted (discarded/undersized/protected) individuals of the commercial species being targeted in any particular fishery are included. We have provided information on the outcomes for the retained commercial species/size in some cases, however, but as additional information only and they are not included as part of the main result. For instance, the conservation outcomes of interventions such as "Set commercial catch quotas" or "Restrict the use of a specific gear" for a specific commercial species (for instance cod) are not summarized for the retained, marketable sizes/species, but for undersized individuals of commercial species and any other non-commercial species (i.e. unwanted catch species).

Collie J.S., Hall S.J., Kaiser M.J. & Poiner I.R. (2000) A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology*, 69, 785–798.

Lambert G.I., Jennings S., Kaiser M.J., Davies T.W. & Hiddink J.G. (2014) Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. *Journal of Applied Ecology*, 51, 1326–1336.

Sciberras M., Hiddink J.G., Jennings S., Szostek C.L., Hughes K.M., Kneafsey B., Clarke L.J., Ellis N., Rijnsdorp A.D., McConnaughey R.A., Hilborn R., Collie J.S., Pitcher C.R., Amoroso R.O., Parma A.M., Suuronen P. & Kaiser M.J. (2018) Response of benthic fauna to experimental bottom fishing: a global meta-analysis. *Fish & Fisheries*, 19, 698–715.

Watling L. & Norse E.A. (1998) Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. *Conservation Biology*, 12, 1180–1197.

Spatial and Temporal Management

2.1 Establish long-term fishery closures

- **Four studies** examined the effects of establishing long-term fishery closures in an area on marine fish populations. One study was in each of the Norwegian Sea[1] (Norway), the North Sea[2] (UK), the Gulf of Maine[3] (USA) and the Bismark Sea[4] (Papua New Guinea).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (4 STUDIES)

- **Condition (2 studies):** One replicated, before-and-after study in the Norwegian Sea[1] found that in the five years after the long-term closure of a commercial coastal fishery, the weights of young salmon returning to rivers were higher than before, and weights of older salmon were similar or lower. One site comparison study in the Gulf of Maine[3] found that there were smaller, but similar condition monkfish inside an area closed year-round to groundfish fishing for six to seven years than an area open to all fishing.
- **Abundance (4 studies)**: Two site comparison studies in the Gulf of Maine[3] and Bismark Sea[4] found a higher abundance of only one of seven fish species[4] and lower abundance of monkfish[3] in areas closed to groundfish fisheries for six to eight years, compared to open areas. One of two replicated, before-and-after studies (one controlled) in the Norwegian Sea[1] and North Sea[2] found that there were more young salmon and similar numbers of older salmon returning to rivers than before, in the five years after the long-term closure of a commercial coastal fishery[1]. The other study[2] found that lesser sandeel biomass and density peaked but there was no overall increase in the three years after a long-term fishery closure compared to before.

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One site comparison study in the Bismark Sea[4] found that in an area closed to customary fishing for eight years, six of seven fish species had a lower flight response distance compared to an area open to customary fishing, making them more vulnerable to capture with spear guns.

OTHER (2 STUDIES)

- **Reduction of fishing effort (1 study):** One replicated, controlled, before-and-after study in the North Sea[2] found that long-term closure of a commercial fishery reduced overall fishing effort for lesser sandeel.
- **Commercial catch abundance (1 study):** One replicated, controlled, before-and-after study in the North Sea[2] found that annual sandeel catch rates were varied after the indefinite closure of the commercial fishery in an area.

Background

Long-term closure of fisheries can be established to protect one or more species of key commercially harvested fish that have suffered continued overexploitation. They differ from other area-based closures based either on gear type(s) alone or those implemented in marine protected areas. This is because they generally apply to only one target fishery/species whilst often allowing other commercial fisheries to operate. In addition, closures of target fisheries do not involve legal protection of the seabed/habitat and may thus be more adaptive and easier to impose or even remove, particularly in response to a recovery of the target fish stock. Long-term fishery closures may be applied to protect commercial/harvested species year-round for an indefinite period. They may help depleted populations of fish to recover by reducing the fishing effort and thus mortality exerted upon them.

Evidence for a related intervention is summarized under *'Establish temporary fishery closures.'* See also *'Cease or prohibit all (mobile and static) fishing gears that catch bottom (demersal) species'*.

A replicated, before-and-after study in 1980–1994 of four Norwegian rivers draining to the Norwegian Sea (1) found that in the five years following a long-term ban on a coastal drift net fishery for Atlantic salmon *Salmo salar*, there were increases in the catch abundance and weights of young (one-sea winter) salmon returning to rivers, but fewer changes for multi-sea-winter salmon. In three of four rivers, overall numbers of grilse (young salmon returning from the sea to fresh water for the first time) were higher in the five years after the ban (after: 500–4,000 fish, before: 80–1,200 fish) and numbers of older, multi-sea-winter salmon were similar (after: 50–3,200 fish, before: 50–3,200 fish). Average weight of grilse increased in all four rivers (after: 1,714–2,340 g, before: 1,558–1,996 g), whereas two-sea-winter salmon weights decreased in two (after: 5,769–6,211 g, before: 6,500–6,988 g) and there were no changes for three-sea-winter salmon (after: 9,075–10,764 g, before: 8,938–10,752 g). In addition, effects of the ban on salmon populations returning to four Russian rivers (outside of the ban area) were found for three rivers draining to the Barents Sea, but not for one draining to the White Sea (see paper for data). A total ban on sea fishing for salmon using drift nets was introduced in Norway in 1989, while other methods such as bag and bend nets continued. Data on catches of salmon (mainly rod and line) for four Norwegian rivers (Repparfjord, Alta, Namsen, Stryn) from 1980–1994 were taken from Norwegian Official Statistics.

A replicated, controlled, before-and-after study in 1997–2003 of a seabed area in the North Sea, Scotland, UK (2) found that in the three years after long-term closure of a commercial fishery for lesser sandeel *Ammodytes marinus* there was a peak but no overall increase in the biomass and density of sandeel, overall fishing effort was reduced and catch rates varied. The annual biomass of the two youngest groups of sandeel (young of the year and 1+ year) peaked during the closure (2000–2003) compared to the previous three years, but no overall statistical difference was found between periods (after: 0–233,000 t, before: 0–50,000 t). Similarly, sandeel density peaked in the first year after closure (after: 7–48 fish/m^2, before: 4–42 m^2), but was not statistically different. Fishing effort was reduced each year during the closure (after: 25–50 d, before: 80–280 d) but estimates of catch rates varied (after: 50–190 t/day, 55–130 t/day). In 2000, the sandeel fishery off south-east Scotland was closed indefinitely in response to concerns that seabird colonies were declining from lack of fish prey. Sandeel biomass estimates were derived from acoustic (six transects) and bottom trawl surveys (19 deployments) from a commercial vessel between May–July 1998–2003. Density data were collected from 137–195 grab deployments done each year, and fishing effort and catch data were derived from official fisheries statistics for the Danish commercial sandeel fishery.

A site comparison study in 2004–2005 of two areas of mud and gravel seabed in the Gulf of Maine, USA (3) found that year-round closure of an area to fisheries targeting bottom-dwelling fish (groundfish) for six to seven years, resulted in lower abundance and size of monkfish *Lophius americanus* abundance inside the closure area compared to outside, feeding intensity varied and condition was similar. Overall, monkfish abundance and size were lower inside the closure area than outside (data reported as statistical model results). The abundance of larger monkfish (401–800 mm) was similar inside compared to outside (inside: 0.3–0.8 fish/tow, outside: 0.3–1.2 fish/tow), but was lower for monkfish between 0–400 mm (inside: 0.3–0.8 fish/tow, outside: 1.3–2.7/tow). Stomach fullness of adult monkfish was higher inside (10 g/mm^3), than outside (6 g/mm^3), but juvenile (<300 mm) stomach fullness was similar (inside: 8 g/mm^3, outside: 11 g/mm^3). Monkfish condition was similar across protection levels (data reported as statistical model results). In addition, monkfish feeding intensity and condition were generally more strongly affected by habitat type than the closure. In autumn 2004 and spring 2005, a total of 32 otter trawl deployments were conducted at paired sampling sites, rock/cobble edge and mud, inside and outside, of the Western Gulf of Maine Closure

Area. The area was closed to groundfish fishing in 1998, initially to reduce fishing mortality of key groundfish species such as cod. Monkfish were counted, lengths measured, weighed and stomach content recorded.

A site comparison study in 2008 at two reefs in the Bismark Sea, Papua New Guinea (4) found that long-term closure of areas to traditional fisheries (those with customary fishing rights) resulted in greater abundance of only one of seven species compared to fished areas after eight years, and the flight response of six species decreased. Striated surgeonfish *Ctenochaetus striatus* were more abundant inside closed areas compared to fished areas (closed: 47, open: 25 fish/1,000 m^2), but abundances of the other six species (orange-lined triggerfish *Balistapus undulatus,* Bleeker's parrotfish *Chlorurus bleekeri,* daisy parrotfish *Chlorurus sordidus,* yellowbarred parrotfish *Scarus dimidiatus,* dusky parrotfish *Scarus niger,* and humpback red snapper *Lutjanus gibbus*) were similar (inside: 1–31, outside: 1–14 fish/1,000 m^2). In addition, flight response of all but one species (humpback red snapper) inside the closure area was shorter (closed: 131–365 cm, open: 207–551 cm), making them more vulnerable to capture by spear guns (range 1.3 to 3.1 m). Fish were surveyed on reefs off Karkar Island inside and outside one site (0.5 km^2) that at the time of the study had been closed to customary fishing (using spear guns and hand lines as primary gear types) for 8 years, with the exception of a 2-week period during which it was opened to fishing for a ceremonial feast (details of when sampling took place were not reported). The community maintains a customary system of reef management where a portion of the reefs is closed for several years when the clan chiefs decide fish are staying out of the range of spear guns. Sampled reefs outside the closure area had not been closed to fishing. At five locations at each site, two, 50 × 5 m belt transects at 2–4 and 6–8 m depths were surveyed by underwater visual census. Fish flight distance was measured by placing weighted markers on a measuring tape at the start position of the fish and the final position after disturbance.

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(2) Greenstreet S.P.R., Armstrong E., Mosegaard H., Jensen H., Gibb I.M., Fraser H.M., Scott B.E., Holland G.J. & Sharples J. (2006) Variation in the abundance of sandeels *Ammodytes marinus* off southeast Scotland: an evaluation of area-closure fisheries management and stock abundance assessment methods. *ICES Journal of Marine Science*, 63, 1530–1550.

(3) Smith M.D., Grabowski J.H. & Yund P.O. (2008) The role of closed areas in rebuilding monkfish populations in the Gulf of Maine. *ICES Journal of Marine Science*, 65, 1326–1333.

(4) Feary D.A., Cinner J.E., Graham N.A.J., & Januchowski-Hartley F.A. (2010) Effects of customary marine closures on fish behaviour, spear-fishing success and underwater visual surveys. *Conservation Biology*, 25, 341–349.

2.2 Establish temporary fishery closures

- **Five studies** examined the effects of establishing temporary fishery closures on marine fish populations. Two studies were in the North Atlantic Ocean[2,4] (Canada, UK) and one study was in each of the North Sea[1] (UK), the Philippine Sea[3] (Palau) and the Mediterranean Sea[5] (Spain).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One before-and-after, site comparison study in the Atlantic Ocean[4] found no increase in the biomass of the spawning stock of cod following a temporary fishery closure compared to fished areas over nine years.
- **Survival (1 study):** One before-and-after, site comparison study in the Atlantic Ocean[4] found no change in the survival of cod[4] following a temporary fishery closure compared to fished areas over nine years.
- **Condition (1 study)**: One before-and-after, site comparison study in the Atlantic Ocean[4] found no change in the length composition of cod following a temporary fishery closure, compared to fished areas over nine years.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** A study in the Northeast Atlantic Ocean[2] reported that over five years tagged adult cod spent nearly a third of time inside a seasonally closed cod spawning area during implementation, and were thus given increased protection from any gears targeting bottom-dwelling fish during the spawning period.

OTHER (4 STUDIES)

- **Reduction of fishing effort (1 study):** One replicated, controlled, before-and-after study in the North Sea[1] found that fixed temporary closures had little effect on fishing effort for cod, but real-time area closures reduced the annual amount of cod caught (retained and discarded).
- **Commercial catch abundance (3 studies):** One of two replicated (one controlled, one before-and-after) studies in the Philippine Sea[3] and Mediterranean Sea[5] found that during a temporary closure of a grouper fishery, spear fisher catch numbers of other fish groups (herbivores) increased, indicating they were being targeted more compared to the open season[3]. The other study[5] found that in targeted fisheries over 10 years, catch rates of red mullet and total catch (fish and invertebrates combined), but not European hake, increased after temporary closures, compared to before. One before-and-after, site comparison study in the Atlantic Ocean[4] found no change over nine years in cod catches following a temporary fishery closure compared to fished areas.

Background

Like long-term fishery closures, temporary fishery closures in an area can provide relief from fishing mortality to selected species or groups of species that have suffered commercial overexploitation. Unlike long-term fishery closures, temporary closures can be seasonal (occurring in an area during a specific time) or rotational (areas alternately closed and opened to fishing). Seasonal fishery closures may typically be implemented to coincide with known periods during which fish may be more susceptible to the impacts of fishing (e.g. during breeding or spawning). During these periods, many fish species are known to aggregate into denser groups of individuals and may be made up exclusively of individuals of one sex and/or stage of maturity. Rotational fishery closures may be implemented to temporarily reduce fishing effort and mortality on the whole fish population in an area. Prohibiting some or all fishing activity temporarily in an area may protect adult breeding and spawning activity, protect immature fish during settlement and nursing, and reduce fishing mortality, potentially allowing exploited fish populations to recover over time.

Evidence for similar interventions is summarized under *'Establish long-term fishery closures*'. and '*Protect Reproductive Individuals - Protect spawning fish from capture*'.

A replicated, controlled, before-and-after study in 2008–2009 of a large bottom fished area in the North Sea, off northeast Scotland, UK (1) found that fixed temporary seasonal area closures had little effect on reducing fishing effort for Atlantic cod *Gadus morhua* during implementation, but real-time area closures reduced overall cod landings and discards. A reduction in the number of vessels operating within the fixed closure areas (45–69 days) was found in only one of three areas, compared to the 14 days before closure (during: 3 vessels, before: 8 vessels) and was lowest in the 14 days after closure (1 vessel), while for the other two closure areas, vessel activity was similar (during: 2–4 vessels, before: 3–4 vessels, after: 1 vessels). A fourth area closed initially for four months (1 December 2008 to 31 March 2009) was kept closed for at least a year because test catch rates of cod exceeded the threshold set for re-opening. In addition, separate real-time closures implemented in 2009 resulted in estimated overall annual reductions in cod catch (landings and discards) of 707 t. Seasonal (total of four) and real-time (maximum of 12 at any one time, closed for 21 days when cod catch rate threshold exceeded) closures were implemented for Scottish vessels in 2008 and 2009 to control fishing effort and reduce mortality and discarding of cod (activity by non-Scottish vessels not required to adhere to closures was recorded). Data were collected in 2008–2009 from landings and monitoring systems of vessels fishing in and around the closure areas.

A study in 2007–2012 of a seabed area in the Gulf of St. Lawrence, Northeast Atlantic Ocean, Canada (2) found that over five years tagged adult cod *Gadus morhua* showed frequent and long-term use of a seasonally closed spawning area established for five years that prohibited fishing for bottom dwelling fish, and thus had increased protection from fishing. Data were not statistically tested. Tagged adult cod spent an average 28% of time (range 0–72%) inside the closed area during its enforcement period and were at liberty for 224–746 days before capture, indicating long-term survival. Movement patterns of different groups of cod indicated that migratory cod used the area more extensively (13–72%) than non-migratory cod (0%). In addition, 17 tags from the 353 adult cod tagged were returned (i.e. captured; the fate of the other 336 is unknown). A closed area of 5,000 km^2 was implemented in 2002 prohibiting all ground fishing activities yearly from April 1st to June 15^{th}. Between 2007–2012, a total of 353 cod were captured using baited handlines and surgically implanted with data storage tags. Of the 17 tags returned, complete data from 14 were used to reconstruct cod movements.

A replicated, controlled study in 2009 of reef fisheries in the Philippine Sea, Palau, Micronesia (3) found that the implementation of a temporary closed season for groupers *Serranidae* resulted in higher spear fisher catch rates of herbivorous fish by number but not by weight, compared to the open season, and indicated an increase in the targeting of these species by spear fishers. Average catch numbers of herbivorous fish actively targeted by spear fishers throughout the year were higher during the closed grouper season (7 fish/person/h) than the open season (4 fish/fisher/h), but there was no difference in catch rates by weight (closed: 4, open: 3 kg/fisher/h). For other groups of herbivorous fish (harvested opportunistically or normally avoided), catch rates were higher during the closed season by both number (closed: 2.2, open: 0.6 fish/fisher/h) and weight (closed: 1.6, open: 0.5 kg/fisher/h). Since 1994, a closed season (April–July) for five grouper species was implemented to protect spawning fish. In 2009, daily surveys of reef fish landings were done at Koror fish market for two weeks during the open (18–31^{st} March) and closed (13–26^{th} July) grouper fishing seasons. Nineteen spear fisher catches during the closed season and 23 during the open season were sampled and ranked by category of herbivorous fish based on information given by the fishers: actively targeted

(10 species), opportunistically harvested (24 species) and avoided (17 species). Species, weight and length was recorded for parrotfishes *Scaridae*, surgeonfishes and unicornfishes *Acanthuridae* and rabbitfishes *Siganidae*.

A before-and-after, site comparison study in 1986–2010 of an area of seabed in the north east Atlantic Ocean, western Scotland, UK (4) found that a seasonal fishery closure implemented during the spawning period resulted in no change in catches, spawning stock biomass, length composition or mortality of Atlantic cod *Gadus morhua* in the nine years following implementation compared to before and to two fished areas. Data were reported as statistical model results. Catch/unit effort and spawning stock biomass of cod decreased after the seasonal closure was implemented, in both the closed area and two fished areas. The length composition of cod was similar between the closed and fished areas and did not change after the closure. Mortality rates differed between areas before and after the closure and intermediate mortality rates were found in the closed area compared to the two fished areas. Annual seasonal fishery closures from 6th March to 30th April were introduced in the Firth of Clyde in 2001 to protect spawning Atlantic cod. Cod were surveyed in one of two zones of the closure area, both closed to gears that target fish but permitted creeling and scallop dredging. Trawling for Norway lobster *Nephrops* was allowed in the surveyed zone but not in the adjacent zone (not surveyed). Cod landings and hours fished by vessels over 10 m along the west coast of Scotland were extracted from the Marine Scotland database. Cod data from within the closure and from two fished reference areas were obtained from scientific bottom trawl surveys for the period 1986–2010.

A replicated, before-and-after study in 2002–2011 of two bottom fishing grounds in the southwestern Mediterranean Sea, Spain (5) found that seasonal fishery closures implemented for 10 years resulted in increased catch rates of red mullet *Mullus* spp. and total catch (fish and invertebrates combined) post-closure, but not European hake *Merluccius merluccius*, compared to before closure. For fisheries targeting red mullet, overall catch rates of red mullet (after: 162–407, before: 130–146 kg/vessel/day) and total catch (after: 1,526–1,898, before: 991–1,017 kg/vessel/day) were higher after closures, in both seasons. For hake fisheries, closures did not affect hake catch rates (after: 6–7, before: 5–6 kg/vessel/day) or the total catch rates (after: 18,679–22,406, before: 17,114–19,655 kg/vessel/day) in either season, but total catch rates varied between years. Annually from 2002–2011 in the Gulf of Alicante, seasonal fishery closures of one month/year were implemented in both northern and southern areas, the closure month alternating between areas normally from May-June and September-October. Fisheries landings data (species and weights) for all years were obtained from two ports (Dénia in the north and La Vila Joiosa in the south) and the data from five years (2004, 2006–2008 and 2010) used to estimate catch rates of species targeted as part of multi-species trawl fisheries before and after the closures.

(1) Holmes S.J., Bailey N., Campbell N., Catarino R., Barratt K., Gibb A. & Fernandes P.G. (2011) Using fishery-dependent data to inform the development and operation of a co-management initiative to reduce cod mortality and cut discards. *ICES Journal of Marine Science*, 68, 1679–1688.

(2) Le Bris A., Fréchet A. & Wroblewski J.S. (2013) Supplementing electronic tagging with conventional tagging to redesign fishery closed areas. *Fisheries Research*, 148, 106–116.

(3) Bejarano Chavarro S., Mumby P.J., Golbuu Y. (2014) Changes in the spear fishery of herbivores associated with closed grouper season in Palau, Micronesia. *Animal Conservation*, 17, 133–143.

(4) Clarke J., Bailey D.M. & Wright P.J. (2015) Evaluating the effectiveness of a seasonal spawning area closure. *ICES Journal of Marine Science*, 72, 2627–2637.

(5) Samy-Kamal M., Forcada A. & Lizaso J.L.S. (2015) Effects of seasonal closures in multi-specific fishery. *Fisheries Research*, 172, 303–317.

2.3 Cease or prohibit all commercial fishing

- **Eight studies** examined the effects of ceasing or prohibiting all commercial fishing in an area on marine fish populations. Two studies were in the Tasman Sea[2,8] (Australia), and one was in each of the Indian Ocean[4] (Australia), the Mediterranean Sea[1] (Spain), the Greenland Sea[3] (Iceland), the Gulf of Mexico[5] (USA), the South China Sea[6] (China) and the south Atlantic Ocean[7] (South Africa).

COMMUNITY RESPONSE (3 STUDIES)

- **Community composition (3 studies):** Two before-and-after studies (one site comparison) in the Tasman Sea[2] and South China Sea[6] found that the fish assemblage/species composition was different before and after prohibiting all commercial fishing, in an estuary after two years[2], and in the nearby wider region surrounding two marine reserves five years after their creation[6]. One site comparison study in the South Atlantic Ocean[7] found no change in species composition between a reserve closed to all commercial fishing for 40 years and unprotected fished areas.
- **Richness/diversity (2 studies)**: One site comparison study in the South Atlantic Ocean[7] found no difference in overall fish diversity between a protected area closed to all commercial fishing for 40 years compared to unprotected fished areas. One before-and-after study in the South China Sea[6] found that fish species richness decreased in the wider region five years after all commercial fishing was banned in two marine reserves.

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies)**: Two of four site comparison studies (one replicated, one before-and-after) in the Mediterranean Sea[1], Indian Ocean[4], South Atlantic Ocean[7] and the Gulf of Mexico[5] found that in protected areas prohibiting all commercial fishing for five years[4] and 40 years[7] there were higher abundances of three of 12 commercially targeted and non-targeted fish species/groups[4] and one of four commercially targeted fish species[7], compared to unprotected fished areas. One study[5] found mixed effects on fish densities 30–40 years after banning all commercial fishing, varying with level of commercial exploitation, and higher abundances of five of five commercially exploited species. The other study[1] found there was no increase in white seabream and gilthead bream biomass 2–13 years after closure compared to an unprotected fished area, but it was lower than a no-take area protected for over nine years. One before-and-after, site comparison study in the Tasman Sea[2] found that most fish species in an estuary in a marine reserve had a lower abundance two years after it was closed to all commercial fishing than before, as did one of two reference sites in unprotected adjacent estuaries. One before-and-after study in the South China Sea[6] found that in the five years after the creation of two marine reserves with limits on commercial fishing activity, overall fish density in the nearby wider region increased. One replicated, site comparison study in the Tasman Sea[8] found that in areas of a marine reserve closed to commercial trapping, fish abundance varied over 10 years and was higher for some groups than others compared to reserve sites open to trapping.
- **Condition (1 study):** One replicated, site comparison study in the Indian Ocean[4] found that in marine reserve areas banning all commercial fishing for five years, overall fish size was bigger compared to fished areas.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, controlled study in the Greenland Sea[3] found that areas closed to commercial fishing (trawling) had higher recaptures of tagged smaller immature cod than adult cod over time compared to trawled areas, indicating they were more likely to have an increased protection from fishing.

Background

Commercial fishing is extraction of marine organisms by any method for sale and profit. It is one of the most widespread human activities in our seas and oceans, and its biggest direct impact on fish is the potential removal of huge quantities of target fish species over large areas. Commercial fishing is done with nearly every gear type, many of which are not highly selective, catching unwanted fish that cannot be sold and so are returned to the sea, often dead or with reduced survival prospects (Benoit *et al.* 2013; Depestele *et al*. 2014). If left uncontrolled, commercial fishing can cause depletions, or even total collapse, of entire fish populations (Hutchings & Reynolds 2004; Dickey-Collas *et al.* 2010). Ceasing or banning all commercial fishing in an area can significantly reduce the overall fishing pressure to levels that should allow commercially targeted fish populations to recover from over-fishing or to maintain existing healthy levels. Prohibiting commercial fishing types may also indirectly benefit non-commercially targeted fish species by reducing disturbance and damage to habitats by the gears used. This intervention is often, but not always, implemented in marine protected areas.

Evidence for similar interventions relating to the ceasing or prohibiting of commercial fishing activity by different gear types is summarized throughout the *'Spatial and Temporal Management'* section.

Benoit H.P., Plante S., Kroiz M. & Hurlbut T. (2013) A comparative analysis of marine fish species susceptibilities to discard mortality: effects of environmental factors, individual traits, and phylogeny. *ICES Journal of Marine Science*, 70, 99–113.

Depestele J., Desender M., Benoit H.P., Polet H. & Vincx M. (2014) Short-term survival of discarded target fish and non-target invertebrate species in the "eurocutter" beam trawl fishery of the southern North Sea. *Fisheries Research*, 154, 82–92.

Dickey-Collas M., Nash R.D.M., Brunel T., van Damme C.J.G., Marshall C.T., Payne M.R., Corten A., Geffen A.J., Peck M.A., Hatfield E.M.C., Hintzen N.T., Enberg K., Kell L.T. & Simmonds E.J. (2010) Lessons learned from stock collapse and recovery of North Sea herring: a review. *ICES Journal of Marine Science*, 67, 1875–1886.

Hutchings J.A. & Reynolds J.D. (2004) Marine Fish Population Collapses: Consequences for Recovery and Extinction Risk. *BioScience*, 54, 297–309.

A site comparison study in 1992–2005 of three rocky areas in the northwest Mediterranean Sea off the coast of Spain (1) found that two to 13 years after commercial fishing was prohibited in a partially fished zone of a marine reserve, there was no increase in the biomass of white seabream *Diplodus sargus* and gilthead bream *Sparus aurata* compared to an unprotected fished area. Across all years, the average biomasses of white and gilthead bream were similar between partially fished (white: 5.9 g/m^2, gilthead: 0.1 g/m^2) and fished areas (white: 6.1 g/m^2, gilthead: 0.2 g/m^2). However, both were lower compared to a no-take zone of the reserve, unfished for over nine years (white: 19.1 g/m^2, gilthead: 0.8 g/m^2). Fish were sampled annually from 1992–2005 at three nearby sites, up to 2 km apart: a partial reserve (angling permitted only, no collection of subtidal animals since 1990); a fished stretch of coastline; and a no-take reserve in the Medes Islands Marine Protected area (no extractive activities, since 1983). Numbers of fish at each site were recorded by underwater visual transects (no further sampling details were provided).

A before-and-after, site comparison study in 2001–2005 of a mangrove and saltmarsh estuary in the Tasman Sea, New South Wales, Australia (2) found that two years following closure to commercial fishing, there was a different fish assemblage and lower abundance of most species compared to before the closure, and a similar change was found at one of two reference sites in adjacent estuaries. The fish assemblage at the estuary closed to commercial fishing differed before and after closure and overall abundances (mangrove and saltmarsh habitats combined) of only two of the 12 main fish species increased, while the rest decreased (data reported as statistical results - see original paper). The fish assemblage at one of two reference sites in similar nearby estuaries also differed following the closure and no change was observed at the other (data reported as statistical results). The authors suggested that the reported decline in abundance may have been due to an increase in predation by larger fish after the closure. Botany Bay was closed to commercial fishing (netting and trapping) in mid-2002. Fish were surveyed at the Towra Point Nature Reserve in Botany Bay and two nearby reference sites (no details of fishing activity were reported), in June-August and December-February immediately prior to (2001–2002) and two years after (2004–2005) the closure. Fish were sampled using 4 m fyke nets set at 50 m intervals: four replicate deployments in saltmarsh habitat and two in mangroves/site before the closure, increased to three deployments in mangroves after.

A replicated, controlled study in 1994–1995 of five areas of seabed in the Greenland Sea, off northwest Iceland (3) reported that prohibiting all or some commercial fishing in marine protected areas and other areas closed to trawling, provided more protection from fishing for immature cod *Gadus morhua*, whose movement patterns indicate they are relatively stationary, but not for the migratory adults. The spatial distribution of recaptured cod over time was similar for all sites and tagging years, and there were no differences between cod tagged inside protected areas compared to outside (data reported graphically). However, there were clear seasonal and size-based differences over time, and the proportion of small cod recaptured at sizes <55 cm was lower for the area with the highest level of protection from fishing (4–9%) than most of the fished areas (7%, 21% and 25%), and the other marine protected area (15%). In addition, for small cod but not large cod, distance from areas of higher fishing intensity may also have influenced recapture patterns. Tagging surveys took place within five areas in July 1994 and June 1995 using two types of conventional tags. A total of 5,173 small cod (40–54 cm) were tagged in five areas: a marine protected area closed permanently to commercial fishing since 1993 (1,687 cod); a protected area closed to otter trawling and longlining since 1993, but open to a seasonal fishery (Oct-Mar) since 1997 (572 cod); two nearby inshore areas closed to trawling (1,916 cod); and one nearby area with no fishing restrictions (998 cod). Data on cod recaptures were analysed from a subset (224, anchor tags only) of the 719 (14%) tag returns made by fishers to the Marine Research Institute from 1994–2000. Most recaptured fish (78–94%, depending on tagging area) were caught in the first 3 years after tagging.

A replicated, site comparison study in 2005 of five coral reef sites in the Indian Ocean, off the coasts of South Africa and Mozambique (4) found that five years after prohibiting commercial fishing in partially protected areas of two marine reserves, there was an increased abundance of three of 12 commercially targeted and non-targeted fish species/groups, compared to unprotected fished areas, and overall, fish were larger. Average abundance was higher in the partially fished areas than openly fished areas for groupers *Epinephelinae* spp. (0.7 vs 0.3 fish/count), yellow-edged lyretail *Variola louti* (0.3 vs 0.1 fish/count) and butterflyfish *Chaetodontidae* (3.2 vs 2.6 fish/count). Similar abundances between areas were recorded for snappers *Lutjanus* spp. (0.3 vs 0.5 fish/count), two-spot red snapper *Lutjanus bohar* (0.1 vs 0.0 fish/count), emperorfish *Lethrinidae* (0.1 vs 0.0 fish/count), surgeonfish *Acanthuridae* (6.2 vs 10.0), goldbar wrasse *Thalassoma hebraicum* (2.3 vs 1.9), grunts *Plectorhinchus* spp. (0.1 vs 0.2) and parrotfish *Scaridae* (1.1 vs 1.3). In partially fished areas abundances were lower than in openly fished areas for green jobfish *Aprion viriscens* (0.0 vs 0.3 fish/count) and jacks *Caranx/Carangoides* spp. (0.3 vs 2.1 fish/count). Average fish size (reported a standardised measure) was higher in partly fished (58) than openly fished areas (48). In April 2005, fish were sampled at four partly protected areas (limited non-commercial/non-trawl fishing types and diving permitted, next to no-take reserve areas) of two adjacent marine reserves (designated 1999), and at five openly fished sites outside the reserves (two adjacent and three >200 km away). At each site, divers counted selected fish species >7 cm in length, along two replicates of bisecting transect pairs 25 m long and 5m wide. Point counts (22–32) were also conducted at each site in a 5 m radius, separated by 20 m. Data were analysed for seven coral-dominated sites (three part protected and two open).

A before-and-after, site comparison study in 1999–2011 of a large managed reef area in the Gulf of Mexico, Florida, USA (5) found that fish densities in an area of a marine reserve where commercial fishing had been prohibited for over 30 years, varied with level of commercial exploitation over a ten-year period and immediately following conversion of half of the area to no-take (no fishing), and abundances of five of five commercially exploited species were greater compared to adjacent openly fished areas. For five of five commercially targeted fish, increases in density were detected in 2–7 surveys (out of 7) in the non-commercially fished area and there were no decreases, while in the fished areas an increase in density was detected in one of four surveys and density decreased in two to three. For 11 non-target fish species, five species collected for the aquaria trade and two protected groupers *Epinephelus* spp., changes in density fluctuated between years in both areas (see paper for species individual data). In addition, adult percentage abundances of the five commercial species increased overall in the non-commercially fished area from baseline levels (1999–2000) of 49–71% to 54–87% in 2008–2010 (a year after half of the area was made no-take), while abundances in openly fished areas showed overall decreases (1999–2000: 9–27%, 2008–2010: 1–23%). Fish were monitored in two areas of the Dry Tortugas region with different levels of management protection: Dry Tortugas National Park (~320 km^2, fishing prohibited except hook and line angling since the 1960s; half of the area designated as no-take in 2007) and an area with open access to commercial and recreational fishing. Both areas were adjacent to other no-take reserves. Baseline fish surveys were done in 1999–2000 (two surveys) and monitoring surveys every one or two years from 2002–2011 (seven surveys in non-commercially fished and four in fished areas). A total of 8,106 diver visual counts were done in a two-stage stratified random sampling design. Numbers of reef fish were recorded in randomly selected circular plots 15 m in diameter.

A before-and-after study in 1994–2005 of a large area of soft, shelly mud seabed in the South China Sea, Hong Kong, China (6) found that after prohibiting commercial fishing in two protected marine reserves as mitigation for a large-scale land reclamation project, fish species composition in the wider region changed, overall fish density increased but species richness decreased, in the five years after implementation. Fish species composition changed in the period after both reserves were established (2001–2005) compared to before (1994–1999) (data reported as graphical analysis). Fish densities in the region were higher overall after both reserves were established than before (after: 97,000–280,000 fish/km^2, before: 11,000–12,000 fish/km^2), but peaked in 2003 before declining in 2004 and 2005. Over the same period, fish species richness decreased (after: 84–103, before: 127–140 species). Between December 1992 and early 1996, a huge coastal development to reclaim 9.4 km^2 of land from the sea north of Lantau Island was completed in the study area. To reduce impacts on dolphin habitats, two nearby and adjacent marine reserves (12 km^2 and 460 km^2) were created in December 1996 and October 1999 respectively, zones of which prohibited commercial fishing and other human activities. Fish were sampled at 1–6 sites/survey in an area up to 10 km from the reclaimed land by beam trawl (total 882 deployments), annually from 1994–1995 and 1999–2005. Catch data from sampling sites, including one in the smaller of the reserves, were pooled for each year.

A site comparison study of an area of reef, sand and kelp in the South Atlantic Ocean, off the coast of South Africa (7) found that prohibiting commercial fishing in a marine protected area for 40 years increased the abundance of one of four commercially targeted fish species compared to unprotected fished areas outside, but did not increase overall fish diversity or change species composition. Average abundance was higher inside the non-commercially fished area than outside for hottentot *Pachymetopon blochii* (inside: 5.0, outside: 2.6 max. number) and was similar between areas for roman seabream *Chrysoblephus laticeps* (1.3 vs 0.9 max. number), panga seabream *Pterogymnus laniarus* (6.7 vs 4.3 max. number) and carpenter seabream *Argyrozona argyrozona* (1.6 vs 1.1 max. number). Numbers of species, diversity (Shannon-Wiener values) and overall fish species composition were similar inside (no. species: 34, Shannon-Wiener: 1.73) and outside (no. species: 39, Shannon-Wiener: 1.43) the non-commercially fished area. Fish were surveyed inside and outside the Betty's Bay Marine Protected Area (20 km^2, commercial fishing prohibited but recreational fishing allowed since 1973). Four steel baited remote underwater video cameras were simultaneously deployed for one hour at 30 stations within and 28 stations in adjacent areas outside the protected area. For each video camera, all fish species and the maximum number of any species in a single frame 35 cm off the seabed and centred on a bait canister 1 m away were recorded. The earliest the survey took place was in 2012 but no details of sampling times were provided.

A replicated, site comparison study in 2002–2012 of eight rocky coral reef sites in the Tasman Sea, New South Wales, Australia (8) found that in areas of a marine park where commercial trapping was prohibited, there was a higher abundance of some fish species or groups over a 10 year period following implementation, compared to park areas open to commercial trapping. Abundances varied between years, but overall average abundances of two of 10 targeted fish species/groups and one of two non-targeted groups were higher at non-commercially fished areas than commercially fished areas, one targeted species was lower and the rest were similar between areas (data reported as statistical results and presented graphically for some species only). Fish assemblages were monitored annually in 2002–2007, 2009 and 2012, at eight sites, in the Solitary Islands Marine Park: two sites in each of two management areas where recreational fishing but no commercial fish trapping was permitted (>200 ha); and four sites in areas where commercial trapping and recreational fishing were permitted. The park was originally designated in 1991 and rezoned in 2002. At each site, fish were surveyed by six underwater visual transects (125 m^2) and three replicate five-minute timed-swim counts (250 m^2).

(1) Rius M. & Zabala M. (2008) Are marine protected areas useful for the recovery of the Mediterranean mussel populations? *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18, 527–540.

(2) Saintilan N., Mazumder D. & Cranney K. (2008) Changes to fish assemblages visiting estuarine wetlands following the closure of commercial fishing in Botany Bay, Australia. *Aquatic Ecosystem Health & Management*, 11, 441–449.

(3) Schopka S.A., Solmundsson J., Ragnarsson S.A. & Thorsteinsson V. (2010) Using tagging experiments to evaluate the potential of closed areas in protecting migratory Atlantic cod (*Gadus morua*). *ICES Journal of Marine Science,* 67, 1024–1035.
(4) Currie J.C., Sink K.J., Le Noury P. & Branch G.M. (2012) Comparing fish communities in sanctuaries, partly protected areas and open-access reefs in South-East Africa. *African Journal of Marine Science*, 34, 269–281.
(5) Ault J.S, Smith S.G, Bohnsack J.A., Luo J., Zurcher N., McClellan D.B., Ziegler T. A., Hallac D.E., Patterson M., Feeley M.W., Ruttenberg B.I., Hunt J., Kimball D. & Causey B. (2013) Assessing coral reef fish population and community changes in response to marine reserves in the Dry Tortugas, Florida, USA. *Fisheries Research*, 144, 28–37.
(6) Tam Y-K., Ni I-H., Yau C., Yan M-Y., Chan W-S., Chan S-M. & Lu H-J. (2013) Tracking the changes of a fish community following a megascale reclamation and ensuing mitigation measures. *ICES Journal of Marine Science*, 70, 1206–1219.
(7) Roberson L., Winker H., Attwood C., De Vos L., Sanguinetti C. & Götz A. (2015) First survey of fishes in the Betty's Bay Marine Protected Area along South Africa's temperate south-west coast. *African Journal of Marine Science*, 37, 543–556.
(8) Malcolm H.A., Jordán A., Creese R.G. & Knott N.A. (2016) Size and age are important factors for marine sanctuaries: evidence from a decade of systematic sampling in a subtropical marine park. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 26, 1090–1106.

2.4 Cease or prohibit all (mobile and static) fishing gears that catch bottom (demersal) species

- **Three studies** examined the effects of ceasing or prohibiting mobile and static fishing gears that catch bottom (demersal) species in an area on marine fish populations. One study was in each of the Greenland Sea[1] (Iceland), the North Pacific Ocean[2] (Canada) and the North Atlantic Ocean[3] (USA/Canada).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies)**: One of three replicated, controlled studies (one paired) in the Greenland Sea[1], North Pacific Ocean[2] and the North Atlantic Ocean[3] found that an area where fishing gears targeting bottom-dwelling species had been prohibited for 15 years had higher numbers of larger and older cod than openly fished areas[3]. One study[1] found that fish densities in areas closed to mobile and static bottom fish gears (trawls and longlines) for at least 11 years varied between fish species/groups, and also with depth and temperature. The other study[2] found that prohibiting mobile and static bottom fish gears (trawls and hook and line) in protected areas for 2–7 years had no effect on fish densities compared to non-protected areas.
- **Condition (2 studies):** One of two replicated, controlled studies (one paired) in the Greenland Sea[1] and the North Atlantic Ocean[3] found that cod had better growth in areas closed for 5-15 years to mobile and static gears that targeted bottom-dwelling fish, compared to openly fished areas[3]. The other study[1] found that fish size varied between areas closed and open to bottom fish gears (trawls and longlines) and was also affected by depth and temperature.

BEHAVIOUR (0 STUDIES)

Background

Fishing gears that target fish or invertebrate species that live and feed mostly on or near the seabed (collectively called demersal or groundfish species) consist of a variety of gears, both mobile and static. Mobile gears include those actively towed on or just above the seabed by vessel, such as most types of trawls and some seine nets, and bottom seine nets pulled or drawn in by hand or vessel. Static gears include those when deployed on or near the bottom such as gillnets and longlines. These fishing gears not only selectively remove target and non-target bottom-dwelling fish species or groups, but some can cause disturbance and damage to sensitive bottom habitats, including those that fish may depend on for activities such as spawning. Ceasing or prohibiting some or all mobile and static fishing gears that catch bottom species in an area may protect demersal fish communities from overexploitation, reduce fishing mortality and help to preserve essential fish habitats.

Evidence for similar interventions relating to the use of different fishing gears to target bottom-dwelling fish are summarized under *'Cease or prohibit mobile fishing gears that catch bottom (demersal) species and are dragged across the seafloor'*, *'Cease or prohibit fishing shellfish dredging'*, *'Cease or prohibit line fishing'* and *'Cease or prohibit spearfishing'.* See also, '*Establish long-term fishery closures*' and *'Establish temporary fishery closures'*.

A replicated, paired, site comparison study in 2004–2005 of three seabed areas in the Greenland Sea, off the coast of Iceland (1) found that three marine protected areas closed to bottom gears (trawls and longlines) for at least 11 years had different fish densities and sizes of the most abundant bottom dwelling species, compared to adjacent areas outside, but the effect of depth or temperature was stronger than level of protection. Differences in fish density (mean log number) by size group were found inside areas closed to bottom gears compared to outside for two of nine species/groups in the closed area on the northwest coast, and for four of six in the other two closure areas on the northeast coast (see paper for species individual data). In the northwest, average fish size was similar between areas for eight of nine fish species/groups and smaller for one in the closed area; and for the two northeast areas, three of six fish species/groups were smaller inside one of the closure areas compared to the other and outside, and there were no differences for the other three (see paper for species individual data). However, the influence of temperature or depth on fish density and average size between closed and open areas was found in many cases to be higher than the level of protection (see original paper). Fish sampling was done by a research trawler: in August 2004 inside and outside one protected area off the northwest coast (41 trawl deployments); and in July 2005 inside two adjacent protected areas and one unprotected area off the northeast coast (47 deployments). The protected areas were established primarily to protect small cod and were closed to trawling and fishing with longlines in 1993 (two had been closed to trawling since the early 1970s and 1992).

A replicated, controlled study in 2009–2011 of four seabed areas in the northeast Pacific Ocean, off Canada (2) found that prohibiting bottom trawls as well as commercial and recreational hook and line fishing in protected areas for two to seven years, did not result in different densities of six of six fish species compared to outside. Densities did not differ for quillback *Sebastes maliger* (inside: 0.04 fish/100 m^2, outside: 0.04 fish/100 m^2), yelloweye *Sebastes ruberrimus* (inside 0.02 fish/100 m^2, outside 0.02 fish/100 m^2), copper *Sebastes caurinus* (inside 0.03 fish/100 m^2, outside 0.04 fish/100 m^2), lingcod *Ophiodon elongatus* (inside 0.02 fish/100 m^2, outside 0.03 fish/100 m^2), kelp greenling *Hexagrammos decagrammus* (inside 0.04 fish/100 m^2, outside 0.04 fish/100 m^2) and greenstriped rockfish *Sebastes elongatus* (inside 0.02 fish/100 m^2, outside 0.02 fish/100 m^2). Areas inside and outside 35 Rockfish Conservation Areas in four regions of southern British Columbia were surveyed 30 times by a remotely operated camera vehicle in 2009–2011. Data were collected during daylight from paired transects 300–900 m long inside and outside the protected areas. Fish density was calculated from fish counts and size of surveyed area. The Rockfish Conservation Areas were established between 2004–2007 and prohibited bottom trawl fisheries and commercial and recreational hook and line fisheries. Fisheries for invertebrates by trap and hand, and seining, gillnetting and mid-water trawling were permitted.

A replicated, paired, controlled study in 2007–2009 of four bottom fishing grounds in the Gulf of Maine and Georges Bank, North Atlantic Ocean, USA (3) found that prohibiting fishing gears that target bottom-dwelling fish (groundfish) for between five and 15 years, resulted in higher numbers of larger and older cod *Gadus morhua* and improved growth, compared to openly fished areas. Across all sites, in areas closed to bottom fishing gears, average cod length (inside: 55.6 cm, outside: 50.0 cm) and age (inside: 3.3 y, outside: 2.8 y) was higher, more cod age >5 were found (inside: 47, outside: 5) and cod growth was higher (data reported as growth functions and coefficients). At individual sites, cod length was significantly higher at two of four sites, and age at one. From 1994–2002, five year-round closed areas (22,000 km^2) were implemented in the Gulf of Maine and Georges Bank prohibiting certain commercial bottom gears, primarily trawls and gillnets. Other fishing activities such as recreational fishing, and scallop dredging and longlining in special access areas was allowed. Four of the five closed areas were sampled from late spring to early autumn 2007–2009. Cod were collected at by rod and reel from inside (n=520) and outside (n=316) >5km away from the boundaries. Cod length, total weight and weight of removed organs was recorded, and ages determined from the otoliths (ear organs).

(1) Jaworski A., Solmundsson J. & Ragnarsson S.A. (2010) Fish assemblages inside and outside marine protected areas off northern Iceland: protection effects or environmental confounds? *Fisheries Research*, 102, 50–59.

(2) Haggarty D.R., Shurin J.B. & Yamanaka K. L. (2016) Assessing population recovery inside British Columbia's Rockfish Conservation Areas with a remotely operated vehicle. *Fisheries Research*, 183, 165–179.

(3) Sherwood G.D. & Grabowski J.H. (2016) A comparison of cod life-history parameters inside and outside of four year-round groundfish closed areas in New England, USA. *ICES Journal of Marine Science*, 73, 316–328.

2.5 Cease or prohibit mobile fishing gears that catch bottom (demersal) species and are towed across the seafloor

- **Ten studies** examined the effects of ceasing or prohibiting mobile fishing gears that catch bottom (demersal) species and are towed across the seafloor on marine fish populations. Two studies were in each of the North Atlantic Ocean[1,6] (Canada, Portugal), the Indian Ocean[3,10] (Tasmania, Kenya) and the Mediterranean Sea[7,9]. One study was in each of the North Sea[2] (Denmark), the Arafura Sea[4] (Australia), the Coral Sea[5] (Australia) and the Gulf of Mexico[8] (USA).

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies)**: Two of three site comparison studies (one replicated and randomized, and one before-and-after) in the North Sea[2], Indian Ocean[3] and Gulf of Mexico[8] found that the number of fish species[3], the fish assemblage and overall species richness and diversity (fish and invertebrates combined)[8] varied between areas with different exposures to bottom trawling, and was also dependent on bottom depth[3] and habitat type[8]. The other study[2] reported no effect of closing an area to all towed bottom fishing gears on the species richness of bottom-dwelling fish after 10 years and compared to areas open to trawling.

POPULATION RESPONSE (8 STUDIES)

- **Abundance (5 studies)**: Two of three replicated studies (one controlled and before-and-after, and two site comparison) and one of two before-and-after studies (one site comparison) in the North Sea[2], Arafura Sea[4], North Atlantic Ocean[6] and the Mediterranean Sea[7,9] found that ceasing or prohibiting fishing with towed bottom gears resulted in higher total fish biomass after 15 years[9], higher biomass of adult red mullet after 14 years[7] and increased abundances of long-snouted, but not short-snouted, seahorses after one year[6], compared to openly fished areas. The other two studies[2,4] found that a ban on towed bottom fishing gears for five[4] and 10 years[2] had no effect on the abundance of bottom-dwelling fish species after closure compared to before[2], or the abundance and biomass of fish and invertebrate species (combined) compared to areas open to towed gears/trawling[4].
- **Reproductive success (2 studies):** One of two before-and-after studies (one site comparison) in the North Atlantic Ocean[1] and Mediterranean Sea[7] found that after the closure of an area to all bottom-towed fishing gears for 14 years, recruitment of young red mullet had increased[7]. The other study[1] found that an area closed to bottom trawling did not have higher recruitment of young haddock seven years after closure and compared to a trawled area.
- **Survival (1 study):** One before-and-after, site comparison study in the North Atlantic Ocean[1] found that closing an area to bottom trawling did not increase the survival of young haddock seven years after closure, and compared to a trawled area.
- **Condition (5 studies):** One of four replicated studies (two site comparison and one randomized, site comparison) and one before-and-after study in the Arafura Sea[4], Mediterranean Sea[7,9], Gulf of Mexico[8] and the Indian Ocean[10] found that areas prohibiting bottom towed fishing gears had larger sizes of adult red mullet 14 years after closure than before[7]. Two studies[8,10] found that the effect on fish size of closing areas to towed bottom gears for 3–6 years[10] or areas with no bottom fishing activity[8] varied between individual fish groups[10] and with habitat type[8], compared to fished areas. The other two[4,9] found that areas closed to bottom trawling for five years[4] and 15 years[9] had no effect on the overall size of fish and invertebrate species combined[4] or average fish weight[9], compared to trawled areas.

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduce unwanted catch (1 study):** One randomized, replicated, site comparison study in the Coral Sea[5] found no reduction in the biomass of non-commercial unwanted catch (fish and invertebrate discard) or in the number of 'common' and 'rare' discard species in areas closed to trawling for seven years compared to trawled areas.
- **Catch abundance (1 study):** One replicated, before-and-after study in the Indian Ocean[10] found that areas prohibiting beach and all other seine nets for 3–6 years found overall fish catch rates were higher, and catch rates of individual fish groups were variable, compared to unrestricted areas.

Background

Mobile bottom-towed fishing gears targeting demersal species (mainly various trawl types and some seine nets) are nets that are hauled or actively towed in contact with the seabed, usually from one or more vessels under power (and hence they are a specific subset of general bottom/demersal fishing gears – see related interventions listed below). Towed mobile bottom-contacting gears typically consist of a conical length of net that gradually tapers in size from a wide opening at the front to a closed end section (codend) that collects the catch. Towed bottom-contacting gears can be deployed over large linear distances for extended periods of time and so can catch large quantities of fish, including unwanted sizes and species. Because they are dragged along the seabed essential fish habitats may be damaged along with non-target fish and organisms that fish may feed on. They can also cause sediment disturbance that reduces water quality (Jones 1992). Banning mobile fishing gears that contact the seabed in an area may reduce overall fishing mortality and the damage and disturbance affecting fish and their habitats.

Evidence for similar interventions relating to the use of towed bottom-contacting fishing gears are summarized under *'Cease or prohibit all (mobile and static) fishing gears that catch bottom (demersal) species'* and *'Cease or prohibit shellfish dredging'*.

Jones J.B. (1992) Environmental impact of trawling on the seabed: a review. *New Zealand Journal of Marine and Freshwater Research,* 26, 59–67.

A before-and-after, site comparison study in 1970–1994 of two areas on the Scotian Shelf, northwest Atlantic Ocean, Canada (1) found that closure of a haddock nursery area to mobile bottom (groundfish) fishing activity did not increase the survival or recruitment of young haddock *Melanogrammus aeglefinus* in the seven years after compared to before, and compared to a fished area. Average rate of haddock survival to age two was lower in the closed area in the period after closure compared to before, but it did not differ in the fished area (data presented as survival index). Conversely, trends in haddock recruitment at age two before and after the closure were similar in both areas. Authors noted possible causes for the effect, including continued fishing in the closure area by fixed gears, and biological and environmental factors. In 1987, a haddock nursery area on the Emerald and Western Banks (4,000 nm^2) was permanently closed to mobile groundfish fishing activity, whilst fixed gears were permitted until 1993 when the area was closed to all fishing including fixed gear. The closed area was 13% of the total area of the Northwest Atlantic Fisheries Organization haddock management unit Division 4VW. This unit was compared with a neighbouring fished area without a closure (4X). Haddock numbers and age data for the years 1970–1994 were taken from annual July research vessel surveys in the two areas.

A before-and-after, site comparison study in 1981–1998 of a fjord in the North Sea, Denmark (2) reported that prohibiting all towed bottom fishing gears in an area had no effect on the abundance and species richness of bottom-dwelling fish in the following 10 years, and compared to open areas. Data were not statistically tested. In trawl surveys, fish abundance (closed: 0–13 kg/30 min, open: 0–31 kg/30 min) and number of species (closed: 4–11, open: 1–9) varied between years but no effect of the closure was detected in either area. In set net and trap samples, catch rates were higher in the fished area (closed: 37–486 g/fishing unit, fished: 132–915 g/fishing unit) but there was no difference in the number of species (closed: 3–8, fished: 4–8). In 1988, a 40 km^2 fishing area in the Limfjord (previously fished commercially using poundnets, trawls – types unspecified – but most recently and extensively by mussel dredges) was closed to all towed fishing gears (in practice however the ban was focussed on stopping mussel dredging as little or no other towed gears were being used, static gears allowed). Fish data was collected by two methods: annual trawl surveys from 1981–1998 in August/September at two stations inside and two just outside the closed area; and in 1995, 1996 and 1997, experimental fishing with fixed set nets (48 deployments) and eel traps (38 deployments) at three locations inside and three outside the closed area. Catch rates and number of species were recorded. No fish species groups (other than demersal) or individual species were specified.

A site comparison study in 1997 of 14 seamounts in the Indian Ocean, Tasmania (3) reported that the number of fish species varied with historical levels of bottom trawling intensity but was also dependent on seamount depth. Data were not statistically tested. The total number of species of fish recorded/seamount was three for non-trawled seamounts, five for very lightly trawled (1–10 trawls), 12/for lightly trawled (11–100 trawls), seven for heavily trawled (101–1,000 trawls) and zero for very heavily trawled (>1,000 trawls) seamounts. In addition, the non-trawled and very lightly trawled seamounts were generally the deepest and therefore considered less likely to support high species richness. In January and February 1997, fish were sampled with longlines, traps and sleds across 14 seamounts off South Tasmania with peaks between 714–1,580 m depth (deployment numbers not given). The seamounts had been trawled at different fishing intensities and in 1995, a temporary protected area incorporating six seamounts with no or very low trawling was established in which the fishing industry agreed not to trawl for a 3-year period. Trawl samples were taken inside and outside the temporary protected area and across the different trawling intensities. Fishing intensity for the period 1988–1996 was obtained from fisher logbook records.

A replicated, site comparison study in 1998 in the Arafura Sea off Australia (4) found that in an area closed to bottom (prawn) trawling for five years, abundance, biomass and size of species (fish and invertebrates combined) were typically similar to two open trawled areas. Probability of occurrence was similar in the closed area and a nearby open area for 81–89% of species, and for 74–85% of species between the closed area and a nearby open area and a distant open area. Biomass was similar in the closed area and the nearby open area for 89–94% of species and similar for 85–99% of species in the closed area, the nearby open area and a distant open area. The average size of species was similar between closed and open areas for 39% species. Zero to 9% of species were largest in the closed area and 43–77% in the two open areas. Sampling was done in October 1998 in two regions of a large area (6,648 km^2) closed to trawling (types not specified) and in 1983 in an area fished and managed for a commercial prawn species. In each region three areas, one closed to trawling and two open to trawling (near to and distant to the closed area) were sampled by a bottom prawn trawl with 57 mm mesh net and 45 mm mesh codend towed for 0.5 h. Three 6 × 6 nautical mile grids were sampled in each area, with each grid sampled three times in each of four three-day sampling blocks. Full sampling details are provided in the original study.

A replicated, randomized, site comparison study in 1992–1993 in four areas of mixed seabed inside the Great Barrier Reef Marine Park in the Coral Sea, Australia (5) found no difference in the biomass of non-commercial unwanted catch (fish and invertebrate discard) or in the number of 'common' and 'rare' discard species between areas closed to trawling for seven years and adjacent open fished areas. Data were reported as statistical model results. An extensive area (10,000 km^2) of the Great Barrier Reef Marine Park was closed to trawling (types unspecified) in 1985. Two surveys were carried out, one in 1992 and one in 1993. During each survey, 25 randomly selected sites were sampled at each of four areas within the marine park, two closed areas, and two fished areas located 10 nm away, using both a benthic dredge and a prawn trawl. A total of 156 dredges (86 in closed areas, 70 in fished areas) and 122 trawls (68 in closed areas, 54 in fished areas) were deployed. For each tow, discard species were collected, identified, counted, and weighed from subsamples (amount not specified). Total weight of discard was estimated from the subsamples. Species were either recorded as 'common' (found in at least 11 of the 25 sites) or 'rare'.

A replicated, controlled, before-and-after study in 2000–2002 of 17 sites in a lagoon in the North Atlantic Ocean, Portugal (6) found that densities of long-snouted seahorse *Hippocampus guttulatus*, but not short-snouted seahorse *Hippocampus hippocampus*, increased when bottom seine fishing (a mobile gear) was ceased, compared to sites where seining fishing effort remained constant. At sites where experimental seining was ceased after one year, the average density of long-snouted seahorses increased to 0.07 from $0.03/m^2$ and was higher than fished and unfished sites ($0.03/m^2$) in both years. However, densities of short-snouted seahorses decreased (0.02 to $<0.01/m^2$) and were lower than fished and unfished sites (ceased: $<0.01/m^2$, fished: $0.02/m^2$). Experimental fishing was done in the Ria Formosa coastal lagoon in southern Portugal using a beach seine in October 2000–October 2002. A total of 12 sites were seined each month during the first year, but no seining was done at these sites during the second year. Three other sites were fished monthly in both years and two sites were unfished (not seined in either year). All sites were surveyed once each year from June–September by scuba divers using standard underwater visual census techniques along three belt transects 30 m long and 2 m wide (180 m^2/sampling site). Sea horse species were counted, and trunk lengths recorded. Full survey specifications are detailed in the original paper.

A before-and-after study in 1985–2005 of muddy and sandy-mud seabed in the Mediterranean Sea, Sicily (7) found that after the closure of an area to all towed bottom fishing gears for 14 years, adult (spawning-stock) red mullet *Mullus barbatus* had a higher biomass, were larger at two of three depths and recruitment of young mullet increased, compared to before the closure. Biomass of adult red mullet was higher at all depths after the ban (750–4,200 g/haul) compared to before (170–650 g/haul). Average total length of all adult red mullet was higher after the closure at the two depths >50 m, and similar at depths <50 m (data reported as statistical model results). In addition, the number of small fish surviving to reach a larger (fishable) size (i.e. recruitment to the fishery) increased after the closure, and there were several recruitment events recorded throughout the year compared to only one before the closure. In 1990, an area of 200 km^2 in the Gulf of Castellammare was closed to trawl nets and all other bottom-towed fishing gear (non-towed bottom gears and pelagic gears permitted). Red mullet data for the periods before (1985–1986) and after (2004–2005) the closure were obtained from 35 experimental trawl survey deployments at three depth ranges (10–50, 51–100 and 101–200 m).

A randomized, replicated, site comparison study in 2004–2005 on fishing grounds in the Gulf of Mexico, USA (8) found that areas not exposed to bottom trawling had different fish assemblages compared to trawled areas, and the effect on overall species diversity and richness (fish and invertebrates) and fish size, varied with the habitat type. Overall, the fish community structure for all three habitat types differed between non-trawled and trawled areas (reported as statistical results). Species diversity and richness (fish and invertebrates) differed between non-trawled and trawled areas on sand and shell habitats, but not reef, and were higher on non-trawled shell habitat but lower on non-trawled sand habitat. Average total length of four of the nine most important fish species (see paper for species individual data) was higher in non-trawled areas over sand habitat (non-trawled: 94–124 cm, trawled: 84–118 cm), and five were larger over shell (non-trawled: 114–254 cm, trawled: 91–239 cm). Data was collected quarterly in 2004 and 2005 by standard otter trawl net for groundfish surveys at three random stations over each habitat type (sand, shell and reef), both exposed and not exposed to bottom shrimp trawling (as determined from annual shrimp-trawling effort data). In non-trawled areas 24 deployments (10-minute tow) were done on sand, 48 on shell and 24 on reef. In trawled areas 21, 33 and 21 deployments were done on sand, shell and reef respectively. All fish (144 species) and invertebrates (70 species) caught were counted, weighed and fish lengths measured.

A replicated, site comparison study in 2004–2005 of three gulfs in the Mediterranean Sea, Sicily (9) found that 15 years after bottom-towed fishing gear (commercial trawling) was banned in an area, total fish biomass but not average fish weight was higher compared to gulfs where trawling was permitted. The total biomass of fish was higher in the non-trawled gulf than in the two trawled gulfs, and differences were greatest in smaller size classes (data reported as normalised biomass spectra analyses). Average fish weight was typically similar in non-trawled (61–89 g) and trawled gulfs (62–70 g), except for significantly greater average weight in spring. However, more than 70% of fish above 500 g were from the non-trawled gulf. A ban on trawl nets and all other bottom-towed fishing gear in a 200 km^2 area was implemented in the Gulf of Castellammare, 200 km west of the trawled gulfs, in 1990. Fishing with static gears (trammel and gillnets) by artisanal vessels within the trawl exclusion area continued. All gulfs were subject to the existing country-wide ban on trawling in water <50 m. Fish surveys were carried out over four consecutive seasons in the trawl exclusion gulf from 2004 and in the two trawled gulfs in autumn 2004 and spring 2005. Bottom-dwelling fish were sampled with a benthic otter trawl. At each gulf, random sampling within several 2.25 nm^2 areas, at three depths, was done and lengths and weights of all fish recorded.

A replicated, before-and-after, site comparison study in 1996–2007 of three coral reef areas in the Indian Ocean, off Kenya (10) found that landing sites in two management areas (with and without areas closed to all fishing) where beach and all other seine nets had been prohibited for three to six years, had higher average fish lengths of two of five groups, increased overall fish catch rates and varied catch rates of individual fish groups compared to an unrestricted fishing area. Overall, average length was higher in management areas where seine nets were eliminated than in an openly fished site for goatfish *Mullidae* (managed: 19 cm, open: 13 cm) and parrotfish *Scaridae* (managed: 18–19 cm, open:14 cm), and no differences were found for the other three groupings of rabbitfish *Siganidae,* scavengers *Lethrinidae, Lutjanidae, Haemulidae* and 'rest of catch' (managed: 16–19 cm, open: 14–17 cm) (see paper for separate group averages). In the period after beach seines were eliminated (2002–2007), total catch rates increased from 3.0–3.2 to 3.7–3.8 kg/fisher/day in managed areas and averaged 2.0 kg/fisher/day in the open site. In addition, differences in catch composition were found between areas and catch rates differed for four of the five groups with time and management regime (see original paper for data). Fish data was collected between two and 10 days/month at 10 fish landing sites representing three different management regimes: one intensively managed area (small-mesh beach seine nets prohibited in 2001, next to a 6 km^2 no-fishing protected area); one moderately managed area (most seine nets prohibited in 2001, and all seine nets in 2004, >30 km from an area closed to fishing); and one with no restrictions on gear (seine nets the dominant gear but also hand lines, spear guns gillnets, traps and fence nets used, 1–10 km from an area closed to fishing). Fish were categorized by the five groups used locally to price and sell the fish. Data for the two managed areas were collected 1996–2007 and for the open area data was collected in 2001–2007.

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(2) Hoffmann E. & Dolmer P. (2000) Effect of closed areas on distribution of fish and epibenthos. *ICES Journal of Marine Science*, 57, 1310–1314.
(3) Koslow J.A., Gowlett-Holmes K., Lowry J.K., O'Hara T., Poore G.C.B. & Williams A. (2001) Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series*, 213, 111–125.
(4) Stobutzki I., Jones P. & Miller M. (2003) A comparison of fish bycatch communities between areas open and closed to prawn trawling in an Australian tropical fishery. *ICES Journal of Marine Science*, 60, 951–966.
(5) Burridge C.Y., Pitcher C.R., Hill B.J., Wassenberg T.J. & Poiner I.R. (2006) A comparison of demersal communities in an area closed to trawling with those in adjacent areas open to trawling: a study in the Great Barrier Reef Marine Park, Australia. *Fisheries Research*, 79, 64–74.
(6) Curtis J.M.R., Ribeiro J., Erzini K. & Vincent A.C.J. (2007) A conservation trade-off? Interspecific differences in seahorse responses to experimental changes in fishing effort. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 17, 478–484.
(7) Fiorentino F., Badalamenti F., D'anna G., Garofalo G., Gianguzza P., Gristina M., Pipitone C., Rizzo P. & Fortibuoni T. (2008) Changes in spawning-stock structure and recruitment pattern of red mullet, Mullus barbatus, after a trawl ban in the Gulf of Castellammare (central Mediterranean Sea). *ICES Journal of Marine Science*, 65, 1175–1183.
(8) Wells R.J., Cowan Jr. J.H. & Patterson III W.F. (2008) Habitat use and the effect of shrimp trawling on fish and invertebrate communities over the northern Gulf of Mexico continental shelf. *ICES Journal of Marine Science* 65, 1610–1619.
(9) Sweeting C.J., Badalamenti F., D'Anna G., Pipitone C. & Polunin N.V.C. (2009) Steeper biomass spectra of demersal fish communities after trawler exclusion in Sicily. *ICES Journal of Marine Science*, 66, 195–202.
(10) McClanahan T.R. (2010) Effects of fisheries closures and gear restrictions on fishing income in a Kenyan coral reef. *Conservation Biology*, 24, 1519–1528.

2.6 Cease or prohibit shellfish dredging

- **One study** examined the effects of ceasing or prohibiting shellfish dredging on marine fish populations. The study was in the North Sea[1] (Denmark).

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study)**: One before-and-after, site comparison study in the North Sea[1] reported that 10 years after mussel dredging ceased in an area closed to all towed fishing gears there was no change in species richness of bottom-dwelling fish compared to before and to open areas.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study)**: One before-and-after, site comparison study in the North Sea[1], reported that ceasing mussel dredging in an area closed to all towed gears had no effect on the abundance of bottom-dwelling fish after 10 years, and compared to open areas.

BEHAVIOUR (0 STUDIES

Background

Dredging is done to harvest edible shellfish species (e.g. mussels, clams, scallops, crabs) and is undertaken globally and involves towing a dredge along the seabed. Towed shellfish dredges are usually constructed from a heavy metal frame covered with chain mesh and they vary in size and design depending on the target species. Because of their heavy construction and deployment on the seabed, dredges can cause considerable disturbance, reducing water quality and damaging the seabed, and this has been blamed for decreases in catches of fish (Hoffmann & Dolmer, 2000). They may also capture or damage small unwanted fish. Inside areas where dredging is prohibited, its indirect (disturbance) and direct (fishing mortality) effects on fish are removed, although fishing using other methods may still impact the fish species and populations.

For a related intervention, see *'Cease or prohibit mobile fishing gears that catch bottom (demersal) species and are dragged across the seafloor'*.

Hoffmann E. & Dolmer P. (2000) Effect of closed areas on distribution of fish and epibenthos. *ICES Journal of Marine Science*, 57, 1310–1314.

A before-and-after, site comparison study in 1981–1998 of a fjord in the North Sea, Denmark (1) reported that prohibiting all towed fishing gears (mainly mussel dredges) in an area had no effect on the abundance and species richness of bottom-dwelling fish in the following 10 years, and compared to open areas. Data were not statistically tested. In trawl surveys, fish abundance (closed: 0–13 kg/30 min, open: 0–31 kg/30 min) and number of species (closed: 4–11, open: 1–9) varied between years but no effect of the closure was detected in either area. In set net and trap samples, catch rates were higher in the fished area (closed: 37–486 g/fishing unit, fished: 132–915 g/fishing unit) but there was no difference in the number of species (closed: 3–8, fished: 4–8). In 1988, a 40 km^2 mussel *Mytilus edulis* fishing ground in the Limfjord was closed to all towed fishing gears (to prohibit mussel dredging as the only towed gears in use) and only static fishing gears allowed. Fish data was collected by two methods: annual trawl surveys from 1981–1998 in August/September at two stations inside and two just outside the closed area; and in 1995, 1996 and 1997, experimental fishing with fixed set nets (48 deployments) and eel traps (38 deployments) at three locations inside and three outside the closed area. Catch rates and number of species were recorded. No fish species groups (other than demersal) or individual species were specified.

(1) Hoffmann E. & Dolmer P. (2000) Effect of closed areas on distribution of fish and epibenthos. *ICES Journal of Marine Science*, 57, 1310–1314.

2.7 Cease or prohibit mobile midwater (pelagic) fishing gears

- **One study** examined the effects of ceasing or prohibiting fishing with towed (mobile) midwater fishing gears on marine fish populations. The study was in the Norwegian Sea[1] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Condition (1 study):** One replicated, before-and-after study in the Norwegian Sea[1] found that in the five years after drift netting was prohibited in an area, the weights of young salmon returning to rivers were higher than before, and weights of older salmon were similar or lower.
- **Abundance (1 study)**: One replicated, before-and-after study in the Norwegian Sea[1] found that in the five years after the use of drift nets was prohibited, there were more young salmon returning to rivers than before, and similar numbers of older multi-returning salmon[1].

BEHAVIOUR (0 STUDIES)

Background

Mobile midwater (pelagic) fishing gears are nets deployed in the water column above the seabed, typically used to catch pelagic fish species such as herrings *Clupeidae*, tunas *Thunnus* spp. and salmon *Salmonidae*. They include midwater trawls and semi-mobile gears such as purse seines, ring nets and pelagic drift nets. Mobile pelagic gears are generally considered less damaging to seabed habitats than towed bottom fishing gears as they do not purposefully contact the seabed and thus the impact is reduced. However, they are still capable of catching large numbers of fish of both target and non-target species, and accidental contact with seabed features may still occur. Ceasing or prohibiting fishing with mobile pelagic fishing gears may reduce overall fishing effort and fishing mortality in an area, and subsequently reduce the effects on fish populations.

A replicated, before-and-after study in 1980–1994 of four Norwegian rivers draining to the Norwegian Sea (1) found that in the five years following a ban on drift netting in a coastal fishery, there were increases in the catch abundance and weights of young (one-sea winter) Atlantic salmon *Salmo salar* returning to rivers, but fewer changes for multi-sea-winter salmon. In three of four rivers, overall numbers of grilse (young salmon returning from the sea to fresh water for the first time) were higher in the five years after the ban (after: 500–4,000, before: 80–1,200) and numbers of older, multi-sea-winter salmon were similar (after: 50–3,200 before: 50–3,200). Average weight of grilse increased in all four rivers (after: 1,714–2,340g, before: 1,558–1,996 g), whereas two-sea-winter salmon weights decreased in two (after: 5,769–6,211 g, before: 6,500–6,988) and there were no changes for three-sea-winter salmon (after: 9,075–10,764 g, before: 8,938–10,752 g). In addition, effects of the ban on salmon populations returning to four Russian rivers (outside of the ban area) were found for three rivers draining to the Barents Sea, but not for one draining to the White Sea (see paper for data). A total ban on sea fishing for salmon using drift nets was introduced in Norway in 1989, while other methods such as bag and bend nets continued. Data on catches of salmon (mainly rod and line) for four Norwegian rivers (Repparfjord, Alta, Namsen, Stryn) from 1980–1994 was taken from Norwegian Official Statistics.

(1) Jensen A.J., Zubchenko A.V., Heggberget T.G., Hvidsten N.A., Johnsen B.O., Kuzmin O., Loesnko A.A., Lund R.A., Martynov V.G., Næsje T.F., Sharov A.F. & Økland F. (1999) Cessation of the Norwegian drift net fishery: changes observed in Norwegian and Russian populations of Atlantic salmon. *ICES Journal of Marine Science*, 56, 84–95.

2.8 Cease or prohibit all non-towed (static) fishing gears

- We found no studies that evaluated the effects of ceasing or prohibiting all non-towed (static) fishing gears on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear coming into contact with the seabed. Non-towed or static fishing gear (various types of nets, longlines, pots and traps) are usually considered less damaging than mobile gears (Broadhurst *et al*. 2006). However, they can be deployed in areas inaccessible to towed gears and some types can catch large quantities of fish, including unwanted species and sizes. Ceasing or prohibiting all static gears in an area can remove the direct fishing pressure on marine fish and may reduce unwanted fish catch.

Broadhurst M.K., Suuronen P. & Hulm A. (2006) Estimating collateral mortality from towed fishing gear. *Fish & Fisheries*, 7, 180–218.

2.9 Cease or prohibit line fishing

- **One study** examined the effects of ceasing or prohibiting line fishing in an area on marine fish populations. The study was in the Indian Ocean[1] (South Africa).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study)**: One site comparison study in the Indian Ocean[1] found that prohibiting offshore line fishing and all other boat-based fishing in a zone of a marine protected area resulted in higher abundances of four of four fish species over-exploited by line fishing, compared to two zones where boat-based line and spear fishing was permitted.
- **Condition (1 study):** One site comparison study in the Indian Ocean[1] found that in a zone of a marine protected area closed to offshore line fishing and all other boat-based fishing for two to seven years, four of four fish species over-exploited by line fishing were larger, compared to two zones where boat-based line and spear fishing was permitted.

BEHAVIOUR (0 STUDIES)

Background

Commercial line fishing is catching fish using the relatively simple equipment of a cord (fishing line) attached to a hook. Commercial lines vary in construction material and thickness and range in configuration from a single line with several hooks to hundreds or even thousands of hooks attached to one main line (longline) in groups via shorter lines.

Hooks are baited with animal or synthetic substances to attract the fish and can be deployed anywhere in the water column or on the seabed depending on the habit of the species being targeted. Although a less destructive fishing technique compared to some others, line fishing can lead to over-fishing, particularly in shallow coastal waters where intensity can be high. In addition, longlines can be responsible for high levels of unwanted fish catch as well as incidentally capturing other marine animals and birds. The control or elimination of line fishing in an area may help reduce fishing pressure and unwanted catch and mitigates the effects of removal of target species and sizes.

A site comparison study in 2006–2011 of four coral reef sites in a marine protected area in the Indian Ocean, South Africa (1) found that two to seven years after closing a zone to offshore line fishing and all other vessel-based fishing (including spearfishing), there was a higher abundance and larger size of four coral reef fish species, compared to two adjacent zones where boat-based line and spear fishing was permitted. For all years, individual catch rates of four of four species were higher inside the zone closed to line fishing and other vessel-based fishing than in the zone permitting offshore line and spear fishing: slinger *Chrysoblephus puniceus* (3.1 vs 0.8 fish/angler/h), Scotsman *Polysteganus praeorbitalis* (1.2 vs 0.3 fish/angler/h), poenskop *Cymatoceps nasutus* (0.4 vs 0.2 fish/angler/h) and yellowbelly rockcod *Epinephelus marginatus* (0.6 vs 0.1 fish/angler/h); and average lengths were higher (slinger: 293 vs 240, Scotsman: 415 vs 359, poenskop: 417 vs 380, rockcod: 495 vs 435 mm). The Pondoland Marine Protected Area (800 km^2) was designated in 2004 and has a central 'no-take area' (400 km^2) closed to all offshore (vessel based) exploitation and two adjacent controlled fishing areas where offshore line fishing and spearfishing are permitted. No commercial fishing, such as trawling or long-lining, is permitted anywhere in the protected area. From April 2006 to June 2011, quarterly research angling was conducted at two sites in the no-take zone and two in the nearby exploited zone (6 h angling in each zone) at 10–30 m depth. Data were analysed for four species depleted by line fishing.

(1) Maggs J.Q., Mann B.Q. & Cowley P.D. (2013) Contribution of a large no-take zone to the management of vulnerable reef fishes in the South-West Indian Ocean. *Fisheries Research*, 144, 38–47.

2.10 Cease or prohibit spearfishing

- **Five studies** examined the effects of ceasing or prohibiting spearfishing in an area on marine fish populations. Two studies were in the Mediterranean Sea[2,5] (France, Corsica). One study was in each of the Tasman Sea[3] (Australia) and the Indian Ocean[4] (South Africa). One study was a review of marine reserves around the world[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies)**: Two of three site comparison studies in the Mediterranean Sea[2], the Tasman Sea[3] and the Indian Ocean[4] found that prohibiting spearfishing, and line fishing[4], in protected areas increased the abundances of European seabass and gilthead seabream[2] and of coral reef fish species[4], compared to protected and unprotected fished areas, after two to seven years[4]. The other study[3] found that fish densities differed between spearfished and non-spearfished areas after 10–12 years, and was affected by depth and/or fish size. A review of reef marine reserves around the world[1] reported that two non-spearfished reserves in the northwestern Atlantic had more snappers and grunts after two years in one, and higher densities of reef fish, including snappers and grunts after 20 years in the other, compared to nearby fished reefs.

- **Condition (3 studies):** Two site comparison studies in the Mediterranean Sea[2] and the Indian Ocean[4] found that prohibiting spearfishing, and linefishing[4], in marine protected areas resulted in larger European seabass[2] and coral reef fish species[4], compared to protected and unprotected fished areas, after two to seven years[4]. A review of global reef marine reserves[1] reported that reef fish were larger in one reserve in the northwestern Atlantic that had banned spearfishing for 20 years, compared to nearby fished reefs.

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Commercial catch abundance (1 study):** One replicated, site-comparison study in the Mediterranean Sea[5] found that prohibiting spearfishing in specific zones of a marine reserve resulted in higher commercial and recreational fishery catches of targeted common dentex compared to zones that allowed spearfishing and areas outside the reserve after one to three years.

Background

Spearfishing is a technique of hunting fish underwater, historically with sharpened or barbed sticks, but in current times often using powered metal spearguns. Spearfishing is done by free diving, snorkelling or scuba diving and is one of the few fishing techniques where each target fish is individually selected, and unwanted catch is virtually nil. However, spearfishing is widely used, is an effective and efficient method of harvesting fish and activities may be concentrated at habitats such as reefs. In heavily targeted areas, local fish populations can be severely depleted (Dulvy & Polunin 2004; Godoy *et al*. 2010) or may suffer other impacts related to the removal of particular sizes or sexes of fish (Alonzo & Mangel 2004). Spearfishing activity is managed throughout the world with a wide range of restrictions ranging from complete bans to prohibiting the use of scuba or spearguns or allowing only recreational spearfishing. Prohibiting spearfishing may often be implemented in marine protected areas with the aim of preventing localised overfishing or selective removal of parts of the fish population.

Alonzo S.H. & Mangel M. (2004) The effects of size-selective fisheries on the stock dynamics of and sperm limitation in sex-changing fish. *Fishery Bulletin*, 102, 1–13.

Dulvy N. & Polunin N. (2004) Using informal knowledge to infer human-induced rarity of a conspicuous reef fish. *Animal Conservation*, 7, 365–374.

Godoy N, Gelcich S., Vasquez J.A. & Castilla J.C. (2010) Spearfishing to depletion: evidence from temperate reef fishes in Chile. *Ecological Applications*, 20, 1504–1511.

A review in 1993 of studies of reef marine reserves (1) reported that prohibiting spearfishing in two areas in the north Atlantic Ocean/Gulf of Mexico, off the Florida Keys, USA, resulted in increased abundance of targeted snappers and grunts (species not given) two years after closure, and higher densities and larger lengths of several reef fish, including snappers and grunts after 20 years, compared to nearby fished reefs. Two years after spear fishing was prohibited, abundance of snappers and grunts at Looe Key Reef marine sanctuary increased by 93% and 439% respectively, and in addition, several previously absent species also appeared in the prohibited area which were rare in fished areas. Data for the densities and lengths of reef fish in the Key Largo National Marine

Sanctuary 20 years after spearfishing was prohibited were not provided. Eleven case studies of reef marine reserves across the world were reviewed (search/selection method not reported); two had evidence for the effects of prohibiting spearfishing.

A site comparison study in 1995 of coastal waters in the Mediterranean Sea, southwestern France (2) found that prohibiting spearfishing in a marine reserve for an unknown number of years, resulted in higher abundance and greater length of European seabass *Dicentrarchus labrax* and higher abundance of gilthead seabream *Sparus aurata*, compared to unprotected fished areas. Average abundance of both species was higher inside the reserve (seabass: 3.9 fish/400 m, bream: 0.7 fish/400 m) than outside (seabass: 0.7 fish/400 m, bream: 0.1 fish/400 m). Average length of seabass was higher inside the reserve (381 mm) compared to outside (212 mm). In addition, average length of gilt head bream was lower inside the reserve (379 mm) than outside (400 mm), but this was not tested statistically due to low sample size outside of the reserve. Data were collected in July 1995 over 26 km of coastline with varied habitat types from Cape Bear to Terrimbau Bay. In the centre is the Banyuls-sur-Mer marine reserve (10 km), where spearfishing was banned throughout (year implemented not reported), but other fishing practices were allowed. Snorkellers counted and recorded lengths of all seabass and gilthead bream along 64 transects of 400 m within 5 m of the shore.

A site comparison study in 2002–2004 of four rocky reef areas in the Tasman Sea, New South Wales, Australia (3) found that prohibiting spearfishing inside a marine protected area for 10–12 years resulted in differences in the overall density of targeted reef fishes on shallow but not deep reefs, and individual differences in density were found for only two of seven fish species/groups compared to unprotected reference areas, and the effect varied with fish size. The densities of all sizes of commonly harvested fish differed between protected and non-protected areas at shallow but not deeper depths (data reported as statistical results). Abundance of legal sized (>200 mm), but not small red morwong *Cheilodactylus fuscus* was higher inside the reserve than outside at both shallow (1.3 vs 0.3/200 m^2) and deep (2.8 vs 1.2/200 m^2) reefs, and abundance of legal-sized (>200 mm) yellowfin bream *Acanthopagrus australis* was higher inside than outside at shallow reefs (0.7 vs 0.3/200 m^2) but similar at deep reefs (0.2 vs 0.1/200 m^2). There were no effects of protection on densities of five other groups (see paper for details of groups), but there were differences with depth and sampling time (data reported as statistical models). Spearfishing was banned in January 1992 at the Gordons Bay area (0.1 km^2) of the Bronte-Coogee Aquatic Reserve. Recreational line fishing and collection of rock lobsters and bait weed were permitted but eastern blue groper *Achoerodus viridis* may not be taken by any method. Between November 2002–2004, fish were sampled six times by underwater visual census at one location within the reserve and three reference areas outside (10–80 km away). At each location and at two depths (<3.5 m and 4–12 m), five replicate 40 × 5 m transects were surveyed.

A site comparison study in 2006–2011 of four coral reef sites in a marine protected area in the Indian Ocean, South Africa (4) found higher abundance and larger size of four coral reef fish species in a zone closed to offshore (vessel-based) spearfishing and all other vessel-based fishing, compared to edge zones where only offshore spear and line fishing is permitted. Individual catch rates were higher inside the no-take zone than the fished zone for all four species in each year: slinger *Chrysoblephus puniceus* (3.1 vs 0.8 fish/angler/h), Scotsman *Polysteganus praeorbitalis* (1.2 vs 0.3 fish/angler/h), poenskop *Cymatoceps nasutus* (0.4 vs 0.2 fish/angler/h) and yellowbelly rockcod *Epinephelus marginatus* (0.6 vs 0.1 fish/angler/h), and average lengths were also higher (slinger: 293

vs 240, Scotsman: 415 vs 359, poenskop: 417 vs 380, rockcod: 495 vs 435 mm). In addition, three of the four species (slinger, Scotsman, rockcod) showed increases in size over time (data not tested statistically). The Pondoland Marine Protected Area (800 km^2) was designated in 2004 and comprises a central 'no-take area' (400 km^2) closed to all offshore (vessel based) exploitation. On either side of the no-take zone are two controlled fishing areas where offshore line fishing and spearfishing are permitted. No commercial fishing, such as trawling or long-lining, is permitted anywhere in the protected area. From April 2006 to June 2011, quarterly research angling was conducted at two sites in the no-take zone and two in the nearby exploited zone (6 h angling in each zone) at 10–30 m depth. Data were analysed for four species depleted by line fishing.

A replicated, site-comparison study in 2000–2012 of mixed bottom (rock, sand and seagrass *Posidonia oceanica*) areas inside and outside a marine reserve in the Mediterranean Sea, off Corsica (5) found that catch rates of common dentex *Dentex dentex* targeted by two different fishery types were higher in zones where spearfishing was prohibited for one to three years, compared to a zone that allowed it and/or areas outside the reserve. For the artisanal fishery (small commercial boats), average catch rate differed between all three zones and was highest in the no spearfishing zones (no spearfishing: 99, general: 17, outside: 26 g/50 m net). For recreational fishing activity, average catch rate in the no spearfishing zones was higher compared to the general zone (no spearfishing: 355, general: 56 g/50 m net) (no catch data outside). Bonifacio Strait Natural Reserve (79, 640 ha) was created in 1999 and has four partially protected zones (each encompassing no-take zones) where spearfishing is prohibited but small-scale artisanal (mainly trammel nets and longlines) and other recreational fishing (mainly longlines and hook and line) is permitted. In the rest of the reserve (general zone) spearfishing is allowed. A total of 962 commercial artisanal boats were sampled May-July 2000 to 2012 (except 2009) onboard or on landing, and 459 recreational boats between March-October in 2006, 2008, 2011. Retained dentex catch was recorded by zone fished (inside reserve: partially protected and general zones, and outside reserve), gear type, and fishing effort.

(1) Roberts C.M. & Polunin N.V.C. (1993) Marine Reserves: Simple solutions to managing complex fisheries? *Ambio*, 22, 363–368.

(2) Jouvenel J.Y. & Pollard D.A. (2001) Some effects of marine reserve protection on the population structure of two spearfishing target-fish species, *Dicentrarchus labrax* (Moronidae) and *Sparus aurata* (Sparidae), in shallow inshore waters, along a rocky coast in the northwestern Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 11, 1–9.

(3) Curley B.G., Glasby T.M., Curley A.J., Creese R.G. & Kingsford M.J. (2013) Enhanced numbers of two temperate reef fishes in a small, partial-take marine protected area related to spearfisher exclusion. *Biological Conservation*, 167, 435–445.

(4) Maggs J.Q., Mann B.Q. & Cowley P.D. (2013) Contribution of a large no-take zone to the management of vulnerable reef fishes in the South-West Indian Ocean. *Fisheries Research*, 144, 38–47.

(5) Marengo M., Culioli J.M., Santoni M.C., Marchand B. & Durieux D.H. (2015) Comparative analysis of artisanal and recreational fisheries for *Dentex dentex* in a Marine Protected Area. *Fisheries Management and Ecology,* 22, 249–260.

2.11 Cease or prohibit customary fishing (indigenous fishing for cultural and community needs)

- **One study** examined the effects of ceasing or prohibiting customary fishing in an area, on marine fish populations. The study was in the Bismark Sea[1] (Papua New Guinea).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study)**: One site comparison study in the Bismark Sea[1] found a higher abundance of only one of seven fish species in an area closed to customary fishing for eight years, compared to an area open to customary fishing.

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One site comparison study in the Bismark Sea[1] found that in an area closed to customary fishing for eight years, six of seven fish species had a lower flight response distance compared to an area open to customary fishing, making them more vulnerable to capture with spear guns.

Background

Customary fishing applies to indigenous communities with a traditional connection to the area being fished and is for subsistence and cultural purposes. Customary fishing may have different fishing rules to commercial or recreational fishing; however, the sustainability of fish stocks is still a priority of customary fishing arrangements. In general, the community leader(s) have the responsibility of maintaining the local fishing laws and decisions may be made for cultural or religious reasons as well as in response to changes in fish catches. For example, closures of areas to fishing might be implemented if fish catches are perceived to decrease in the hope that fish might migrate into the fishing grounds whilst maintaining a good population nearby. Measures might be temporary (less than one year) or permanent (more than one year).

A site comparison study in 2008 at two reefs in the Bismark Sea, Papua New Guinea (1) found that permanent closure of areas regulated by traditional fishing rights (customary fishing) resulted in greater abundance of only one of seven species compared to fished areas after eight years, and the flight response of six species decreased. Striated surgeonfish *Ctenochaetus striatus* were more abundant inside closed areas compared to fished areas (closed: 47, open: 25 fish/1,000 m^2), but abundances of the other six species (orange-lined triggerfish *Balistapus undulatus,* Bleeker's parrotfish *Chlorurus bleekeri,* daisy parrotfish *Chlorurus sordidus,* yellowbarred parrotfish *Scarus dimidiatus,* dusky parrotfish *Scarus niger,* and humpback red snapper *Lutjanus gibbus*) were similar (inside: 1–31, outside: 1–14 fish/1,000 m^2). In addition, flight response of all but one species (humpback red snapper) inside the closure area was shorter (closed: 131–365 cm, open: 207–551 cm) making them more vulnerable to capture by spear guns (range 1.3 to 3.1 m). Fish were surveyed on reefs off Karkar Island inside and outside one site (0.5 km^2) that at the time of the study had been closed to customary fishing (using spear guns and hand lines as primary gear types) for 8 years, with the exception of a 2-week period during which it was opened to fishing for a ceremonial feast (details of when sampling took place were not reported). The community maintains a customary system of reef management where a portion of the reefs is closed for several years when the clan chiefs decide fish are staying out of the range of spear guns. Sampled reefs outside the closure area had not been closed to fishing. At five locations at each site, two, 50 × 5 m belt transects at 2–4 and 6–8 m depths were surveyed by underwater visual census. Fish flight distance was measured by placing weighted markers on a measuring tape at the start position of the fish and the final position after disturbance.

(1) Feary D.A., Cinner J.E., Graham N.A.J., & Januchowski–Hartley F.A. (2010) Effects of customary marine closures on fish behaviour, spear-fishing success and underwater visual surveys. *Conservation Biology*, 25, 341–349.

2.12 Allow only small-scale, traditional (artisanal) fishing

- **One study** examined the effects of allowing only small-scale traditional (artisanal) fishing in an area on marine fish populations. The study was in the Adriatic Sea[1] (Italy).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Commercial catch abundance (1 study):** One site comparison study in the Adriatic Sea[1] found that a marine protected area zone allowing only artisanal fishing activity for three years had higher overall commercial catch rates of five of seven species compared to unprotected areas openly fished.

Background

Artisanal fisheries are the commercial component of small-scale coastal fisheries mostly practiced using traditional methods. They are particularly important in some areas such as the Mediterranean where they constitute about 80% of the fishing fleet (Marengo *et al*. 2015). Artisanal fishing uses a large range of gear types and techniques but is typically operated by a single fisher or a pair of fishers. They target a high number of species, but the fishing methods employed are generally low technology and non-destructive. Allowing only artisanal fishing in an area helps to regulate fishing pressure while balancing conservation and socio-economic needs of local communities, many of whom rely on marine resources. Co-management agreements involving the artisanal fishers may also encourage compliance and may be more easily used to adapt the local fishing effort and/or selectivity to avoid overfishing.

Marengo M., Culioli J.M., Santoni M.C., Marchand B. & Durieux D.H. (2015) Comparative analysis of artisanal and recreational fisheries for *Dentex dentex* in a Marine Protected Area. *Fisheries Management and Ecology,* 22, 249–260.

A site comparison study in 2005–2008 of an area of rocky and sandy seabed in the Adriatic Sea off the southeast coast of Italy (1) found that the ‘buffer’ zone of a marine protected area fished only by artisanal commercial fishers for three years using trammel nets, resulted in higher catch rates of five of seven commercial fish species compared to unprotected fished areas outside. Catch rates varied between years but were overall higher inside the buffer zone than outside for: striped red mullet *Mullus surmuletus* (inside: 5–17, outside: 1–3 kg/km net/d); large-scaled scorpionfish *Scorpaena scrofa* (inside: 5–7, outside: 0–1 kg/km net/d); peacock wrasse *Symphodus tinca* (inside: 2–3, outside: 0–1 kg/km net/d); common pandora *Pagellus erythrinus* (inside: 1–2, outside: 0–1 kg/km net/d) and common dentex *Dentex dentex* (inside: 1–2, outside: 0–1 kg/km net/d). Common seabream *Pagrus pagrus* and forkbeard *Phycis phycis* catches were similar (inside: 0–5, outside: 0–1 kg/km net/d). From January 2005 to July 2008, artisanal commercial fishing catches (exclusively using trammel nets) were monitored inside the buffer zone (1,885 ha, artisanal commercial fishing permitted since 2005 under a co-management protocol with local fishers) and in surrounding no-take zones (352 ha) in the Torre Guaceto Marine Protected Area (all fishing banned in the entire area from 2001–2005). Catch rates of the most important species (those contributing most to the differences between areas) were compared from 217 deployments inside the buffer zone and 66 outside over three years.

(1) Guidetti P., Bussotti S., Pizzolante F. & Ciccolella A. (2010) Assessing the potential of an artisanal fishing co-management in the Marine Protected Area of Torre Guaceto (southern Adriatic Sea, SE Italy). *Fisheries Research,* 101, 180–187.

2.13 Allow periodic fishing only

- **One study** examined the effects of allowing fishing only periodically in an area on marine fish populations. The study was in the Coral Sea[1] (Vanuatu).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired, site comparison study in the Coral Sea[1] found that protected areas fished only for short periods over an 18 month to six-year period, had greater biomass than openly fished areas and similar fish biomass as areas permanently closed to fishing for six years.

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Catch abundance (1 study)**: One replicated, paired, site comparison study in the Coral Sea[1] found that protected areas only fished for short periods over an 18 month to six year period, had higher fish catch rates than openly fished areas.

Background

Allowing fishing activity in an area only for limited frequencies and durations (called periodically harvested closures) is a spatial fisheries management strategy to reduce the impacts of overfishing. They are generally locally managed, small fisheries closures that range from being mostly closed, to mostly open to fishing and are widely implemented in Indo-Pacific regions (Goetze 2016). The aims of periodically harvested closures range from conservation of biodiversity to providing benefits to fisheries through increased catches and fish productivity. Their effectiveness at increasing fish productivity may depend on their size, duration of closure and level of compliance (Goetze 2016).

Goetze J. (2016) The effectiveness of periodically harvested closures as a fisheries management strategy. PhD Thesis, The University of Western Australia, 110 pp.

A replicated, paired, site comparison study in 2012 of six coral reef sites in a marine protected area in the Coral Sea, Vanuatu (1) found that closed areas fished only periodically for a short number of days had greater biomass and fish catch rates compared to areas open to fishing and similar fish biomass to permanent no-take reserves closed to fishing for at least six years. The total fish biomass was similar between periodically fished areas (559–567 kg/ha) and no-take reserves (646–835 kg/ha) and both were greater than fished areas (331–378 kg/ha). The biomass and abundance (data not reported) of only one of three individual fish groups (two fishery target and one non-target) differed between areas and was higher in no-take reserves than the other two areas (see original paper for individual data). In addition, commercial catch rates were higher in periodically harvested closures (4 kg/fisher/hr) than regularly fished areas (2 kg/fisher/hr). Data was collected in November–December 2012 in two regions of the Nguna-Pele Marine Protected Area Network. Fish were surveyed by diver underwater census at two locations, each with three adjacent management zones (8 to 16 ha): a periodically fished area open for 1–3 days every 6 months (implemented since 18 months to 6 years); a no-take reserve (no fishing since 2005); and an area open permanently to fishing. At each of the six sites, divers recorded fish species and length along eight, 50 × 5 m transects, before and after harvesting in the periodically fished areas. Catch data was collected from surveys of fishers.

(1) Januchowski-Hartley F.A., Cinner J.E. & Graham N.A.J. (2014) Fishery benefits from behavioural modification of fishes in periodically harvested fisheries closures. *Aquatic Conservation: Marine Freshwater Ecosystems*, 24, 777–790.

2.14 Establish territorial fishing use rights

- **One study** examined the effects of establishing territorial fishing use rights in an area on marine fish populations. The study was in the Pacific Ocean[1] (Tonga).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Reduction of fishing effort (1 study):** One study in the Pacific Ocean[1] found that there was no decrease in overall fishing effort in an area with new territorial fishing use rights and a co-management system, in the five years after implementation.
- **Commercial catch abundance (1 study):** One study in the Pacific Ocean[1] found that in an area with new territorial fishing use rights and a co-management system, total fish catch rates did not increase and catch rates of three of six individual fish groups decreased in the first five years.

Background

Territorial fishing use rights is an area-based way of managing marine resources that gives exclusive harvesting rights to fish in a specified area to certain groups of people.

These are usually allocated to and managed locally by groups of fishers working in a cooperative system. They may also be part of co-management systems with the government under national or regional frameworks. Territorial fishing use areas can be used to control fishing mortality and enforce fisher compliance. The benefits may include resource and habitat conservation and improved community participation and decision-making at a local scale.

A study in 2007–2011 of reef and lagoon areas of an inhabited coral reef island in the Pacific Ocean, Tonga (1) found that after establishing new territorial fishing rights (exclusion of fishers from outside areas) under a new co-management system in an area, total fish catch rates did not increase in the five years after, catch rates of half of the six individual species groups decreased and there was no decrease in overall fishing effort. No differences in total fish catch rates and catch rates of three of six fish groups (*Acanthuridae - Naso spp*., *Holocentridae*, *Lethrinidae*) were found since implementation, but catch rates of the remaining three (*Acanthuridae - Acanthurus spp., Scaridae, Serranidae*) decreased (data reported as statistical results). In addition, no difference in overall fishing effort was found (data reported as statistical results), but the authors reported that this was likely to be due to reduced travel to fishing grounds further away by resident fishers with the new exclusive rights. Co-management formally commenced on the island of 'O'ua (one of 170 Tongan Islands) in 2007, covering a marine area of 4,606 ha, of which 203 ha is a no-take zone. Only residents on 'Ou'a can fish the co-managed area, whereas before, there was access also to fishers from neighbouring islands and small commercial vessels from the main island group. Fish catch landings (species and weight/trip) were sampled each year between 2007–2011 (total 184 records), collected opportunistically from individual fishers (see original paper for fishing types). Catch data from spearfishing only was used for statistical analysis.

(1) Webster F.J., Cohen P.J., Malimali S., Tauati M., Vidler K., Mailau S., Vaipunu L. & Fatongiatau V. (2017) Detecting fisheries trends in a co-managed area in the Kingdom of Tonga. *Fisheries Research*, 186, 168–176.

2.15 Cease or prohibit all types of fishing in a marine protected area

- **Seventy-nine studies** examined the effects of ceasing or prohibiting all types of fishing in a marine protected area on fish populations. Fifteen studies were in the Indian Ocean[2,5,10,20,25,30,32,37,40,43,49,60,61,68,70] (Kenya, Tanzania, South Africa, Mozambique, Madagascar, multiple African countries, Australia). Twelve studies were in the Mediterranean Sea[16,17,21,27,28,34,35,36,47,48,52,71] (Spain, France, Italy). Ten studies were in the Pacific Ocean[3,8,14,29,33,55,57,64,76,77] (New Zealand, USA, Hawaii, New Caledonia, Costa Rica, Tonga, Vanuatu, Solomon Islands). Seven studies were in each of the Coral Sea[11,12,15,44,45,46,63] (Australia, Vanuatu), the Tasman Sea[4,6,9,42,69,73,78] (New Zealand, Australia) and the Atlantic Ocean[19,22,24,31,58,66,67] (Brazil, USA, Puerto Rico, Argentina, South Africa, UK, Canary Islands, Portugal, Turks and Caicos Islands). Four studies were in the Philippine Sea[18,23,62,65] (Philippines). Three studies were in the Caribbean Sea[41,56,75] (Belize, Puerto Rico). One study was in each of the Gulf of Mexico[51] (USA), the Java Sea[54] (Indonesia), the Pacific and Indian Oceans[59] (multiple countries), the Sulu Sea[72] (Malaysia) and the North Sea[74] (Norway). Six studies were reviews of marine reserves (New Zealand[26], Latin America/Caribbean[39], regions unspecified[79] and across the world[1,7,13]).

COMMUNITY RESPONSE (26 STUDIES)

- **Community composition (7 studies):** Seven site comparison studies (two replicated, and one before-and-after) in the Mediterranean Sea[17,21,52], Indian Ocean[30], Philippine Sea[23] and the Atlantic Ocean[38,50] found that protected areas where all fishing had been prohibited for between three and 16 years, had a different fish community composition, compared to fished areas.
- **Richness/diversity (22 studies)**: Fourteen of 20 site comparison studies (eight replicated, one replicated and paired, and one before-and-after) in the Indian Ocean[2,5,20,30,40,49,68], Mediterranean Sea[17,28,34,35,52,71], Philippine Sea[62,65], Tasman Sea[42], Atlantic Ocean[66], Caribbean Sea[41], Coral Sea[46] and the Pacific Ocean[33], found that marine protected areas that had prohibited all fishing for between one to more than 25 years, had higher fish species/richness compared to fished areas[17,20,28,30,33,34,35,40,41,46,52,62,65,72]. Six studies[2,5,42,49,66,68] found similar fish species/richness between one and 20 years after all fishing was banned in protected areas, compared to fished areas. One systematic review in the Atlantic and Pacific Oceans[39] found no difference in species richness between unfished protected areas and fished areas. One replicated, site comparison study in the Indian Ocean[37] found that the effects of prohibiting all fishing on fish species richness/diversity after 15 years varied with the sampling method used.

POPULATION RESPONSE (66 STUDIES)

- **Abundance (64 studies)**: Thirty of 54 site comparison studies (18 replicated, eight replicated and paired, two before-and-after, one paired and before-and-after, and one replicated and before-and-after) in the Indian Ocean[2,5,10,20,30,32,40,43,49,68,37], Atlantic Ocean[19,22,24,31,38,50,58,66,67], Mediterranean Sea[16,17,21,27,28,34,47,48,52,71], Pacific Ocean[3,6,8,55,57], Tasman Sea[4,9,69,73], Coral Sea[11,12,15,44,45,46], Philippine Sea[18,23,62,65], Caribbean Sea[41,56,75], Gulf of Mexico[51], and the Sulu Sea[72], found that marine protected areas that had been prohibiting all fishing for up to 25 years or more, had higher abundances (density and/or biomass) of all fish (total fish biomass[5,20,28,32,40,50,55,71,72], total fish density[28,40,52,71,72]), fishery targeted fish species[17,18,21,24,51,65], non-fishery targeted fish species[18,24] and all or most of the individual fish species/groups monitored[2,3,4,9,10,16,19,27,44,45,46,50,57,62,67,72], except fish densities (all or most)[5,17] and non-fishery targeted species[71], compared to unprotected fished areas and/or partly-fished protected areas. The studies also found that in some cases where the total fish biomass or densities were higher in no-fished areas, the effect varied between individual groups of fish based on species family[5,20,65] and/or position in the food chain[24], commercial target and non-target species[52], fish sizes[52,65], depth[71] and habitat types[45,46,57]. Eight studies[6,8,31,49,56,58,66,68] found that inside protected areas prohibiting all fishing there were similar abundances of all fish[49,56,58], and all or most of the individual fish species/groups monitored[6,8,31,58,66,68], compared to fished areas between one and 20 years after implementation. The other sixteen studies[11,12,15,22,23,30,34,37,38,41,43,47,48,69,73,75] found that the effect of prohibiting fishing in protected areas for three to 20 years on fish abundance varied between fish species or groups and on their fished status (fishery target or non-target)[11,12,15,73] and/or position in the food chain[11,23,41,47,48,75]. One also found that the effect varied with size or age of the protected areas[69]. Five of six reviews (three systematic) across the world[1,7,13], in the Pacific and/or Atlantic Oceans[26,39] and in unreported regions[79] found that non-fished marine reserves with one to 27 years of protection had higher abundances of all fish[1,7,79], all fish and invertebrates combined[39] and blue cod[26] compared to fished areas, but there were differences between species/groups and fishing intensity outside reserves[1]. The other review[13] found that fish abundance varied between species in no-take marine reserves between one and 25 years old, and was affected by food chain position, level of exploitation and duration of protection. One replicated study in the Pacific Ocean[64] found a long-term decline in the abundance/presence of eight of 12 shark and ray species inside an established (>15 years) no-fishing protected area, however enforcement was poor. One before-and after, site comparison study in the Pacific Ocean[33], found no differences in overall fish abundance between a marine reserve closed permanently to fishing for five years and a closed area that was harvested for two years during the same period. One site comparison study in the Coral Sea[63] found that in a no-take zone of an area protected for at least 10 years, fish abundance of four of six fish groups were similar to no-entry and fished zones, but two had lower abundance than the no-entry zone. One replicated, paired, site comparison study in the Tasman Sea[42] found that in a non-fished marine park zone abundance of commercially targeted fish was higher than partly fished zones but lower than unprotected areas after four to eight years.

- **Reproductive success (1 study):** One site comparison study in the Mediterranean Sea[36] found more eggs of four commercially targeted fish species inside a non-fished marine reserve enforced for three years than in fished areas outside the reserve.
- **Survival (1 study):** One site comparison study in the Atlantic Ocean[31] found that prohibiting all fishing in a marine protected area for three years resulted in similar survival of red hind grouper, compared to fished areas.
- **Condition (20 studies):** Two global review studies[1,7] (one systematic) and two systematic reviews in the Pacific Ocean[26] and the Atlantic and Pacific Oceans[39] found that prohibiting all fishing in marine protected areas for one to 27 years resulted in larger fish overall[1,7,39] and larger blue cod[26] compared to fished areas, but there were differences between individual fish families or species[1]. Eight of 11 site comparison studies (four replicated, one before-and-after, one paired, and one replicated and paired) in the Tasman Sea[4,6,9], Pacific Ocean[3], Indian Ocean[10,43], Mediterranean Sea[16], Atlantic Ocean[58,66], Java Sea[54] and the Philippine Sea[62], found that non-fished protected areas had larger fish overall[43] and larger individuals of all or most of the fish species/groups monitored[3,4,6,9,10,16,62], compared to fished areas, after one to 22 years. The other three studies[54,58,66] found similar fish sizes of all or all but one species, compared to fished areas one to 16 years after all fishing was prohibited. Three site comparison studies (one replicated) in the Coral Sea[63], Caribbean Sea[75] and the Atlantic Ocean[22] found that fish size in protected areas that had not been fished for six to more than 20 years, varied between fish species or food chain groups. One site comparison study in the Atlantic Ocean[31] found that red hind grouper were larger, but had similar growth, in an area protected from fishing for three years compared to fished areas. One site comparison study in the Atlantic Ocean[67] found that young lemon sharks in areas protected from fishing for 20 years had similar growth rates, but lower condition, than sharks in unprotected fished areas.

BEHAVIOUR (2 STUDIES)

- **Behaviour change (2 studies):** One replicated, site comparison study in the Pacific and Indian Oceans[59] found that surgeonfish and parrotfish inside established protected areas where fishing was prohibited, showed a similar avoidance response to fishing gears as in fished areas, and this increased with increasing fishing intensity outside the protected areas. One replicated, site comparison study in the Indian Ocean[25] found that in non-fished areas protected for one and 24 years, fish grazing rates were higher compared to fished areas.

OTHER (15 STUDIES)

- **Use (7 studies):** Four of six site comparison studies in the Pacific Ocean[29,77], Atlantic Ocean[53] and the Tasman Sea[78] found that marine protected areas where all fishing had been prohibited for at least five to 15 years, were used for a large proportion of time by shark and ray species[53,77,78] and commercially important reef fish species[29], compared to fished areas, thus were provided protection from fishing. Two other studies[14,70] found that time spent inside areas closed to all fishing for 20 years[70] and over 30 years[14], varied between species and with size for three shark species[70] and with size for giant trevally[14]. One replicated study in the Indian Ocean[60] found that most individuals of five fish species remained inside a marine reserve zone closed to fishing over a nine-year period.

- **Catch abundance (2 studies):** One of two site comparison studies in the Mediterranean Sea[35] and Pacific Ocean[76] found that commercial fish catch rates in small-scale traditional fisheries were highest closest to a marine reserve closed to all fishing for 22 years, and decreased with increasing distance from the reserve. The other study[76] found that there was no increase in fish catch rates in commercially landed catch in the five years after a no-fishing zone was implemented in a co-managed protected area.
- **Stock biomass (1 study):** One replicated, site comparison study in the Indian Ocean[61] found that the stock biomass (the harvested portion of the population) of reef fish species was highest in enforced protected areas closed to all fishing, compared to various other area management regimes.
- **Fishing mortality (2 studies):** Two site comparison studies in the North Sea[74] and Pacific Ocean[77] found that prohibiting fishing in protected areas resulted in reduced commercial fishing mortality of corkwing wrasse tagged inside non-fished marine reserves compared to fished areas[74], and that the overall fishing mortality of grey reef sharks tagged inside protected areas was low[77].

Background

Fishing can impact fish populations directly by species removal or indirectly by changes to the food chain or damage to fish habitats from contact with fishing gears (Collie et al. 2000). Specific marine areas can be given protected status, and the human activities undertaken within the areas managed to control potentially harmful impacts. One such measure is to ban all types of fishing in a protected area. These areas are often known as marine reserves or sanctuaries, or 'no-take' areas. Inside no-take areas, fish are protected from fishing mortality and may allow depleted populations to recover. Fish may also benefit from the reduction in disturbance, particularly during sensitive periods such as spawning, and potential damage to important spawning habitats. Fish that spend a large proportion of time inside no-take protected areas may be expected to have higher protection from fishing mortality than longer-ranging species or individuals, and level of protection may also depend on the size of the protected area (Chateau & Wantiez, 2009).

Evidence for similar interventions relating to prohibiting human activity, including fishing, in marine protected areas is summarized under *'Control human activity in a marine protected with a zonation system of restrictions'*, '*Cease or prohibit all fishing activity in a marine protected area with limited exceptions*' and '*Restrict fishing activity (types unspecified) in a marine protected area*'.

Collie J.S., Hall S.J., Kaiser M.J. & Poiner I.R. (2000) A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology*, 69, 785–798.

Chateau O. & Wantiez L. (2009) Movement patterns of four coral reef fish species in a fragmented habitat in New Caledonia: implications for the design of marine protected area networks. *ICES Journal of Marine Science*, 66, 50–55.

A review in 1993 of 11 case studies of reef marine reserves across the world prohibiting all types of fishing (1) reported that most had increased abundance and size of fish between one and 15 years after protection compared to adjacent fished areas, but there were differences between species or family groups and level of exploitation, and with depth and fishing intensity outside the reserves. Three of four no-take reserves in the Philippines had higher overall fish abundances than fished areas after only one year and in one it had doubled after eight years closure (data not reported). For two reserves in the Caribbean Sea (Belize and Netherland Antilles) established for four years, higher fish densities and average sizes were found for a small number of species, but the biomass of four of five commercially targeted family groups was greater (unfished: 0.1–6.0 kg/count, fished: 0.1–2.0 kg/count), however the effect differed with depth and level of fishing intensity in adjacent fished areas. In a reserve in the Red Sea (Egypt), the effect of prohibiting fishing for 15 years on the abundance and biomass of commercial species was variable and for seven species where they were higher in reserves, average fish weights increased with decreasing fishing intensity (unfished: 42–1,333 g, lightly fished: 41–678 g, fished: 19–447 g). Field studies of reserves were reviewed (search methods not described) and results from sites throughout the tropics discussed.

A site comparison study in 1992–1994 of two protected coral reef areas in the Indian Ocean, Kenya (2) found that prohibiting all fishing in a marine park for up to five years resulted in higher abundances of five of six fish family groups compared to a nearby marine reserve that permits traditional fishing types, but diversity was similar. The abundance of two of three non-commercially fished family groups were higher at the non-fished reef (butterflyfishes *Chaetodontidae*, non-fished: 52–58, fished: 23–40 fish/transect; damselfishes *Pomacentridae*, non-fished: 769, fished 412 fish/transect) and wrasses *Labridae* were similar (non-fished: 56, fished: 52 fish/transect). Abundances of commercially fished groups (emperors *Lethrinidae*, snappers *Lutjanidae* and groupers *Serranidae*) were greater at the no-fishing reef than the fished reef (data were not statistically tested). No differences in fish species number and diversity between non-fished and fished reefs were found (data reported as statistical results). In September-October 1992 and January-March 1994, visual underwater censuses (250 × 10 m transects) of six representative reef fish families were done at a series of sites (number was not reported) at both the Kisite Marine National Park (closed to all fishing types) and Mpunguti Marine National Reserve (traditional fishing such as hand lining and basket trapping only is permitted). Enforcement began in both areas in 1989.

A replicated, site comparison study in 1997 of two areas of coralline flats in the Pacific Ocean, northern New Zealand (3) found that protected areas where all fishing is prohibited had a higher overall density of fish that feed on urchins *Evechinus chloroticus*, and they were larger, compared to adjacent fished areas after 22 years. Data were not tested statistically. The total number of urchin-eating fish was greater in no-fishing areas (161) than fished (76) and they were of larger sizes (data presented as length frequencies). Individually, the densities of four of the eight species were higher in non-fished areas, one was the same and three had very low densities in both areas (see paper for individual data). In December 1997, eight potential fish predators of sea urchins were surveyed by underwater visual census (10 replicates of 25 × 5 m transects) at five sites in Cape Rodney-Okakari Point Marine Reserve (no-take since 1975) and five fished sites in an adjacent area.

A replicated, site comparison study in 1997 of two areas of sand and reef in the Tasman Sea off northeast New Zealand (4) found that prohibiting all fishing in two adjacent marine reserves established for 15 and 22 years, resulted in an increased abundance and size of snapper *Pagrus auratus* compared to adjacent fished areas outside the reserves. Across both reserves, abundances of snapper above the minimum legal length (270 mm) were higher in no-take reserves than fished areas (no-take: 2–5 fish/30 min, fished: <1 fish/30 min) and average total length was greater (no-take: 327 mm, fished: 191 mm). Snapper, as the most abundant predatory fish, were surveyed in October and November 1997 at two no-take reserves: the Leigh Marine Reserve (549 ha, established 1975) and Tawharanui Marine Park, 15 km to the south (350 ha, established 1982). Maximum numbers and estimated length of snapper responding to remotely deployed baited video camera deployments of 30 minutes were recorded. Four replicate deployments were made at six sites inside and six outside the Leigh reserve, and three both inside and outside Tawharanui (72 deployments of 30 mins at 16–24 m depth).

A replicated, site comparison study in 1996 of fifteen patch coral reef sites in the Indian Ocean off east Africa (5) found that prohibiting all fishing in two marine parks for 5 and 22 years resulted in higher total fish biomass and similar fish densities and total species richness compared to unprotected fished reef areas, and there were differences between individual fish family groups. Across both parks, total fish biomass was higher at non-fished (806 kg/ha) than fished (230kg/ha) reefs and individually for seven of eleven fish groups (see paper for data by group). There were no differences in average densities of eight of eight fish groups between non-fished and fished reefs (non-fished: 0–317 fish/500 m^2, fished: 0–609 fish/500 m^2), although higher densities were recorded in non-fished reef areas for 26 of 134 individual species and a lower density for one. Overall species richness was similar at non-fished (40–50 fish/500m^2) and fished (28–39 fish/500m^2) reefs, and higher at non-fished reefs for four of eight family groups (see paper for data by group). Fish were surveyed at five non-fished and ten fished coral reefs sites off southern Kenya and Tanzania (sampling times were not reported). Three non-fished reefs were in the Kisite Marine National Park (10 km^2, no-take since 1974) and two in the Chumbe Island Coral Park (500 m stretch of reef, no-take since 1991). At each reef site the fish assemblage was quantified along two 5 x 100 m transects by two methods: one to estimate wet weight by family group and one to record the number of individuals per species and the number of species per transect. The authors used a non-standard threshold for statistical significance (0.07).

A site comparison study in 1997–1998 of an area of rock and cobble in the Tasman Sea, South Pacific Ocean, off New Zealand (6) found that prohibiting all fishing activity for 4 years in a marine reserve did not result in higher overall abundances of blue cod *Parapercis colias* compared to adjacent fished areas outside, but blue cod inside the reserve were larger. Numbers of blue cod were similar inside the reserve (44 fish/transect) to fished areas (41 fish/transect) at all depths except 20 m. However, the lengths of blue cod inside the reserve were on average 4 cm longer (20–40 cm) than those found in commercially fished areas (21–25 cm). Blue cod were surveyed five times between January 1998 and 1999, at two sites inside the Long Island–Kokomohua Marine Reserve, Marlborough Sounds (619 ha, established as no-take in 1993) and two adjacent (2–4 km apart) fished sites where commercial fishing for blue cod is prohibited but recreational fishing effort can be high. At each site, numbers of cod were recorded during four minute–long diver visual censuses at depths of 5, 8, 11, 14, 17 and 20 m. At each depth, lengths of blue cod were estimated in two-minute time intervals, along a 2 m wide transect.

A systematic review in 2000 of 24 studies of marine reserves across the world (7) found that overall fish abundance was higher, and fish were larger, inside no-take (all fishing types prohibited) reserves with 1 to 26 years of protection, compared to fished areas outside reserves. Overall fish numbers were on average 3.7 times higher inside non-fished reserves than outside. Abundances of fishery targeted species were higher in non-fished reserves than fished areas outside, but non-target species abundance was similar (data reported as statistical model results). Across all species, the effect of protection status (non-fished versus fished) on abundance depended on fish body size; the largest species were over 300% more abundant inside reserves and the effect increased with body size (data reported as model results). The systematic review used data from 24 studies to assess the effects of banning fishing in marine reserves. Twelve of the studies met the criteria for quantitative meta-analysis, the other 12 studies were not included in the meta-analysis.

A replicated, site comparison study in 1998 of eight rocky and sandy sites in the San Juan Archipelago, northwest Pacific Ocean, USA (8) found no differences in the abundances of copper rockfish *Sebastes caurinus,* quillback rockfish *Sebastes maliger,* China rockfish *Sebastes nebulosus* and lingcod *Ophiodon elongatus* between three marine research areas established for eight years where all fishing was prohibited, two areas protected for one year where only fishing for salmon was permitted, and sites open to fishing. Fish abundance data were not provided (reported as statistical results). The authors suggest the lack of increase in fish abundances inside protected areas was likely due to a lack of compliance and enforcement of the restrictions. In July 1998, three marine research reserves (established in 1990 and prohibiting all extractive activities except controlled research collection; sea urchin fishery closed since the late 1970s), two marine protected areas (designated in 1997; voluntary no-take zones where no finfish except salmon can be taken), and three unprotected areas were surveyed. Two divers identified and counted fish along 300 m^2 transects on reef slopes up to 20 m deep (4 transects/site).

A before-and-after, site comparison study in 1992–2001 of an area of shallow rocky reef in the Tasman Sea, New Zealand (9) found that the average density, size and catch abundance of blue cod *Parapercis colias* increased inside a marine reserve in the eight years after all fishing was prohibited, compared to before and recreationally fished areas outside. Cod density was higher inside the unfished reserve than outside from two years after closure (1995) compared to before (1995, inside: 3.2, outside: 1.9 fish/60 m^2; 2001, inside: 6.5, outside: 2.9 fish/60 m^2). Across all years following closure (1993–2000), average length of blue cod was higher in the unfished reserve than fished areas (data reported as statistical model results), and increased over time inside the reserve (2000: 265 mm, 1993: 228 mm) while outside lengths decreased (2000: 71 mm, 1993: 154 mm). Over the same period, experimental catch rates were higher and increased over time inside the reserve compared to outside (data reported as statistical model results). Long Island-Kokomohua Marine Reserve (619 ha) in the Cook Strait was designated as no-take (no-fishing) in April 1993. Blue cod numbers were surveyed annually from March 1992 to April 2001 by underwater visual transects (2 × 2 × 30 m), inside (four/five sites) and outside (four sites) the reserve. Size and catch rates were monitored from September 1993 to April 2000 at three sites inside and six outside the reserve using experimental baited hook and line fishing.

A site comparison study in 1994–1997 of a surf-zone area in the Indian Ocean off the coast of South Africa (10) found that four of four important shore-angling fish species were larger and more abundant in a marine park where all fishing was prohibited for over 16 years, compared to openly fished areas. Average fork lengths were greater inside the no-fishing marine park than fished areas for blacktail bream *Diplodus sargus capensis* (unfished: 284 mm, fished: 226 mm) zebra bream *Diplodus cervinus hottentotus* (unfished: 303 mm, fished: 248 mm) and galjoen *Dichistius capensis* (unfished: 365 mm, fished: 327 mm), and were similar for bronze bream *Pachymetopon grande* (unfished: 358 mm, fished: 354 mm). In addition, catch rates for all species were higher in the marine park (unfished: 4–13, fished: <1–3 kg/100 angler hrs; data were not statistically tested). Fish data were collected from monthly research shore-angling between February 1995 and January 1997 in the Tsitsikamma National Park (80 km of coastline where all fishing is prohibited; shore-angling banned since 1978) and in fished areas extending either side of the park from roving surveys of recreational shore- angler catches between April 1994 and February 1996.

A replicated, paired, site comparison study in 2001–2002 in two coral reef areas of the Great Barrier Reef Marine Park, Coral Sea, Australia (11) found that prohibiting all fishing in no-take zones resulted, after 14 years, in a decline in abundance of six of nine fish species that are prey for the fishery targeted coral trout *Plectropomus* spp. compared to fished zones, while the biomass of coral trout was higher. Average prey fish densities were lower in the no-take than fished zones for six of nine species (no-take: 8–342 fish/site, fished: 12–507 fish/site) and were similar for three (see paper for individual species data). In addition, overall coral trout biomass was greater in the no-take zones (9,790 g/1,500 m^2) than the fished zones (3,420 g/1,500 m^2). Fish data were collected in two areas of the Great Barrier Reef Marine Park using five, 50 × 6 m, belt transects at each site: the Whitsunday Island group was surveyed in December 2001 at eight sites in no-take zones (no fishing permitted, 14 years of protection) and eight in fished zones; and the Palm Island group was surveyed in April 2002 at eight sites in no-take zones (14.5 years of protection) and eight sites in fished zones. Sites were at least 100 m apart.

A replicated, paired, site comparison study in 2001–2002 of three coral reef areas in the Great Barrier Reef Marine Park, Coral Sea, Australia (12) found that prohibiting all fishing in protected areas resulted in a higher biomass and density of two fish species targeted by commercial line fisheries after 14 years, and similar densities of two fish species not targeted by commercial fisheries, compared to nearby fished areas. Biomass and density in the no fishing areas was higher for the commercially fished coral trout *Plectropomus* spp. >35 cm (biomass: 6.6 kg/1,000 m^2; density: 3 fish/1,000 m^2) and Spanish flag snapper *Lutjanus carponotatus* >25 cm (biomass: 5 kg/1,000 m^2; density: 14 fish/1,000 m^2) than fished areas (coral trout: biomass; 1.3 kg/1,000 m^2, density; 1 fish/1,000 m^2; Spanish flag snapper: biomass; 2 kg/1,000 m^2, density; 1 fish/1,000 m^2). The density in the no fishing areas was not significantly different for the non–fished species scribbled rabbitfish *Siganus doliatus* (9 fish/1,000 m^2) and golden butterflyfish *Chaetodon aureofasciatus* (19 fish/1,000 m^2) compared to fished areas (rabbitfish; 13 fish/1,000 m^2, butterflyfish: 19 fish/1,000 m^2). Fish counts and size estimates were recorded by underwater visual surveys between December 2001–October 2002 at three no fishing reserves around the Palm, Whitsunday and Keppel Islands (spanning 600 km of the Great Barrier reef, no fishing for 14 years). Five replicate 50 × 6 m transects were randomly selected at six to 12 sites per protected and fished area, 200–400 km apart from each other.

A review in 2004 of 20 studies of marine reserves across the world (13) found that fish abundance and biomass in no-take marine reserves where all fishing was prohibited for between one to 25 years, varied between species compared to fished reference sites outside reserves, and the response was influenced by food chain position, level of fishing exploitation and duration of protection. Between 5 and 91% of fish species showed strong increases in abundance in no-take reserves compared to fished reference conditions, and 0–36% decreased in abundance. Where there were differences, greater abundances in no-take reserves were found to be associated with five of six food chain groups and for species targeted by fishing or the aquarium trade, with no overall response for non-targeted fish (data reported as response ratios and statistical results). Variation in species responses was also found with time since protection, with abundances of top predators increasing gradually and accounting for greater proportions of the total biomass in the reserves (data reported as response ratios). A literature search for field studies examining the effect of prohibiting all fishing types in no-take reserves on fish communities was carried out. A meta-analysis of data from 20 studies conducted at 31 different locations in which fish abundance and/or biomass for more than 10 individual species had been compared to fished reference sites was done. All studies used visual census (belt transects and point counts) apart from one study that used trammel nets to collect the fish data.

A site comparison study in 1994–1998 in an area of coral reef in the North Pacific Ocean, Hawaii (14) found that the short and long-term movement patterns of tagged and tracked giant trevally *Caranx ignobilis* indicated that a marine reserve where all fishing was prohibited for over 30 years was used by only certain sizes of trevally, and there were frequent movements outside the reserve into fished areas where some were caught by fishers, thus it provided limited protection from fishing. Average size of trevally caught inside the reserve was 28 cm total length (range 14–43 cm) and 22 cm (range 16–37 cm) for those caught outside. Of 289 conventionally tagged trevally 33 fish (11%) were recaptured after an average time at liberty of 346 days (min 2 d, max >7 y). A high percentage (79%) of the recaptured trevally were originally tagged inside the reserve, but only 15% were both tagged and recaptured there, while nearly one third were caught by fishers over 3 km away (up to 70 km). The movement activity of five fish tracked for 9–125 hours showed they spent considerable time inside the reserve but also made frequent movements outside (data reported as minimum convex polygons and kernel home range). Coconut Island (situated on 137,000 m^2 of reef flat, 2.4 km linear perimeter) has been a marine reserve for over 30 years, with a no-fishing zone extending 8 metres seaward from the reef edge. Giant trevally sizes in and around the reserve were collected opportunistically throughout the year between 1994 and 1998 from research fishing. Long-term movements were monitored by recaptures over 9.5 years (dates of tagging were not reported) of 58 conventionally tagged trevally caught by rod and line inside the reserve and 231 caught by traps outside. The short-term movements of five trevally fitted with transmitters were tracked by boat using a hydrophone for periods up to 14 days (sampling times were not reported).

A replicated, paired, before-and-after, site comparison study in 1983–2000 at two coral reef areas in the Coral Sea, Australia (15) found that prohibiting all fishing (no-take) in two marine reserves resulted in an increase in density and biomass of coral trout *Plectropomus* spp. in the period from 3–4 years before establishment to 12–13 years after and compared to fished areas, and higher densities and abundances of fishery targeted species, but not non-target species compared to fished areas 12–13 years after. At both no-take reserves, the average density and biomass of targeted coral trout *Plectropomus* spp. was higher (1999–2000, density: 7–17 fish/1,000 m^2; biomass: 12–16 kg/1,000 m^2) than in pre-protection (1983–1984, density: 2–3 fish/1,000 m^2; biomass: 2 kg/1,000 m^2) and fished areas (1999–2000, density: 3–5 fish/1,000 m^2; biomass: 3 kg/1,000 m^2), the latter two areas being similar. In 1999–2000, average coral density and biomass of a second targeted fish, stripy sea perch *Lutjanus carponotatus* was higher in both reserves than fished areas (density: 12–23 vs 7 fish/1,000 m^2, biomass: 4–5 vs 2 kg/1,000 m^2) but average density and biomass of non-target fish did not differ (density: 56–86 fish/1,000 m^2, biomass: 7–17 kg/1,000 m^2). Reef fish were surveyed by underwater visual census at two island group marine reserves in the Great Barrier Reef Marine Park (no fishing since 1987). In the period before protection, five replicate transects (50 × 20 m) were done in 1983 (one reserve only, 2 sites) and 1984 (both reserves, 2 sites each). In November 1999 to June 2000, no-take and fished zones at both reserves were surveyed by five replicate 50 × 6 m transects (9–12 transects/no-take and fished areas).

A site comparison study in 2002–2003 of three areas of artificial rock in the Adriatic Sea, Italy (16, same experimental set-up as 17) found higher abundances of white seabream *Diplodus sargus*, two-banded seabream *Diplodus vulgaris* and gilt-head seabream *Sparus aurata* at a breakwater in a marine protected area where all fishing had been prohibited for 16 years, and there were more medium and large individuals, compared to two nearby fished breakwaters. The density of white (unfished: 5.0–7.8, fished: 0.0–1.7 fish/125m^2) and two-banded seabream (unfished: 11.6–45.7, fished: 1.0–14.3 fish/125 m^2) was higher at the unfished breakwater than fished ones in two of the four sampling times, and all but small individuals were more abundant (white, small: 0.5 vs 0.0–0.5, medium: 3.7 vs 1.7–1.8, large: 1.8 vs 0.1–0.3; two-banded, small: 0.0 vs 0.0–1.0, medium: 11.1 vs 3.4–3.8, large: 2.2 vs 0.2–0.3 fish/125m^2). Gilt-head seabream were present only at the unfished breakwater in three of four sampling times and were more abundant in the other (unfished: 1.3–2.2, fished: 0.5 fish/125m^2). Fish were surveyed at one breakwater in the Miramare Marine Protected Area (121 ha, no fishing since 1986) and two fished breakwaters (adjacent and 3 km away) four times between spring 2002 to summer 2003. Four underwater visual transects (25 × 5 m) were done at each breakwater. The breakwaters were transplanted boulders 1–3 m wide running parallel to the coast, extending from the surface to depths of 5–8 m.

A site comparison study in 2002–2003 of three areas of artificial rock in the Adriatic Sea, Italy (17, same experimental set-up as 16) found that a breakwater in a marine protected area where all fishing was prohibited for 16 years had a different fish assemblage, a higher species richness, and a similar total fish density but higher density of commercially targeted fish species, compared to two unprotected fished breakwaters. The fish assemblage at the unfished breakwater differed to both fished breakwaters in three of four sampling times, and only one in the final sampling time (data reported as statistical results and graphical analysis). In all four sampling times, species richness was higher at the unfished breakwater (24–27) than fished ones (13–22). Overall fish density was higher at the unfished breakwater in only one of four sampling times, however the individual densities of eight of 12 commercially targeted species were higher at the unfished breakwater in two or more sampling times, and schooling fish density was higher in all four sampling times (data reported as statistical results). The Miramare marine protected area was designated in 1986 and a fishing ban is successfully enforced. Four surveys using two different methods were undertaken from spring 2002 to summer 2003 at one breakwater in the Miramare Marine Protected Area (121 ha, no fishing since 1986) and two fished breakwaters (adjacent and 3 km away). Each sampling time, four transects (25 × 5 m) and four, point counts (5 m radius) were done per breakwater. The authors noted differences in the data between the two census methods.

A replicated, paired, site comparison study in 2002 of four coral reefs off two islands in the Bohol Sea, Philippines (18) found that prohibiting all types of fishing resulted in greater abundance and biomass of commercially targeted fish at one of two marine reserves established for 15–20 years, and higher abundance of non-target fish, compared to nearby fished areas. Abundance and biomass of commercially targeted fish were higher inside Apo marine reserve compared to fished areas (density, inside: 68, outside: 26 fish/500 m^2; biomass, inside: 90, outside: 25 kg/ 500 m^2) and were similar inside and outside Balicasag reserve (inside: 44, outside: 34 fish/500 m^2; biomass data not reported). The abundance of non-commercially targeted fish was greater inside both marine reserves than fished areas (inside: 75–129 fish/ 250 m^2, outside: 90–147 fish/250 m^2). In November and December 2002, fish were surveyed at one site inside and one outside each of the Apo (450 m length of reef, no-take since 1982) and Balicasag marine reserves (650 m long reef, no fishing since 1985, the collection of deep–water ornamental shells is permitted). Fish were surveyed along fifteen 50 × 10 m transects/site: commercial fish 5 m either side (96 species from 13 families) and non–commercial fish 2.5 m either side of the transects (four species of damselfish *Pomacentridae*, 15 species of butterflyfish *Chaetodontidae*).

A site comparison study in 2001–2003 of a reef archipelago in the Atlantic Ocean, Brazil (19) found that young Caribbean reef sharks *Carcharhinus perezi* were more abundant inside a marine protected area where fishing had been prohibited for over 12 years, compared to an adjacent fished area. Average catches of sharks were higher inside the unfished area than the fished (unfished: 0.16 sharks/h, fished: 0.03 sharks/h). Sharks caught in both areas were almost all smaller immature individuals (71–170 cm). Fernando de Noronha Archipelago (26 km^2) is 345 km off the northeastern coast of Brazil and has a marine protected area, no fishing since 1988, around the coastline of its main island out to 50 m water depth. The rest of the area allows fishing and boat traffic. Monthly from March 2001 to February 2003, fishing for sharks was done at 148 randomly selected sites around the archipelago, inside (79) and in the fished area outside (69) the protected area. At each site two baited, single-hook handlines were deployed simultaneously from a small boat. Catch per unit effort of sharks was calculated from the time the first hook was deployed to the time the last hook was removed. Number, length, and sex of captured sharks (143) were recorded.

A replicated, site comparison study in 1996–2004 at seven coral reef sites in the Indian Ocean off Kenya and Tanzania (20) found that in a large permanent no-take zone of a marine protected area where fishing was prohibited for over 20 years, there was higher total fish biomass and species richness, but biomass varied between fish family groups, compared to reefs managed collaboratively for less than 10 years by gear restrictions and temporary fishing closures. Total weight of fish was greater in the area with a permanent no-take zone compared to without in two of two years sampled (weight: 682–1,354 vs 260–457 kg/ha) but the responses differed by individual fish family group (see paper for data), and total number of fish species was higher (with: 47–51, without: 38–41 species/500 m^3). Data were collected from sites in two locations: three reefs in a 10 km^2 area of the Kisite-Mpunguti Marine National Park in Kenya (established 1973) permanently closed to all extractive activities and adjacent to a gear-managed reserve; and four small reefs (0.25–3.0 km^2) in the Mtang'ata Collaborative Management Area in Tanzania (established in 1996) managed by gear restrictions and small voluntarily and temporary closed areas (some illegal fishing reported). At each reef site, fish communities were surveyed twice (in 1996 and 2003–2004) by underwater visual census along two 5 × 100 m belt transects at each site.

A site comparison study in 2004–2005 of a rocky reef island in the Tyrrhenian Sea, off Italy (21) found that prohibiting all fishing in a marine protected area for nine years resulted in a different overall fish assemblage compared to a recreationally fished area, and the abundance of recreationally targeted species was higher at the deeper of two depths. The overall fish assemblage was different between the unfished and fished areas at 5 m and 20 m depths (reported as statistical results). Average number of individuals of species targeted recreationally was higher in the unfished area (9) than in the fished (6) at 20 m depth, but similar at 5 m depth (unfished: 4, fished: 3). Fish were surveyed along 11 km of coastline around Giannutri Island in areas with two different protection levels (established approximately 1993): one where all human activity is banned, and one where commercial fishing is banned but recreational fishing and other activities are permitted. In July and September 2004 and March and May 2005, fish were sampled by visual census at two sites/protection level at 5 m and 20 m depth. Fish within an imaginary cylinder 5 m high and 10 m in diameter were recorded.

A replicated, site comparison study in 2004 of five coral reef sites in the Florida Keys, Atlantic Ocean, USA (22) found that prohibiting all fishing within marine protected areas (no-take) for 6 years resulted in higher biomass, body length and abundance of some reef fish species and sizes, but not others, compared to unprotected fished reefs. The average biomass of one of two species of groupers *Serranidae* spp. and one of three snappers *Lutjanidae* spp. was higher inside (grouper: 1,190; snapper: 910 g/125 m^2) than outside no-take areas (grouper: 130; snapper: 30 g/125 m^2), but was similar for the others (inside: 590–2,400, outside: 100–2,500 g/125 m^2; see paper for individual data). Average body lengths of two of the three snappers were greater in no-take areas, while no differences were found for the other snapper and the only grouper for which there was sufficient data (data reported as statistical results). For three groups of herbivorous fish (see original paper for species), adult sizes of two were more abundant in no-take areas (inside: 0.30–0.98, outside: 0.13–0.74 m^2) and abundances of immature sizes were lower (inside: 0.04–0.60; outside: 0.12–1.50 fish/m^2), while abundance of the other species was similar for both adults and immature fish (inside: 0.05–0.30, outside: 0.03–0.10 fish/m^2). Patch reefs were sampled in three Special Protected Areas (average 0.5 km^2, established 1997, no resource extraction) and at two fished reefs (1 to 3 km apart). Predatory and herbivorous fish were recorded along three 25 × 5 m and 20 × 1 m belt transects, respectively. Predatory fish were surveyed on 5-6 days in June-September 2004 and herbivorous fish on 7–9 days in June-September 2003 and 2004.

A replicated, site comparison study in 1998–2004 of five coral reefs in the Philippine Sea, Philippines (23) found that, over six years, no-take marine reserves in which all fishing had been prohibited for at least one to three years, had different fish communities compared to adjacent and distant fished areas outside, fish abundances varied between species and level in the food chain, and the differences were greater at reserves with the highest enforcement and compliance history. Fish communities differed between all areas (non-fished, adjacent fished and distant fished) and differences between non-fished and adjacent fished areas were strongest at the two of five reserves with the strictest protection levels (data reported graphically and as statistical results). For fish species at the top of the food chain, abundance was higher at two of the five non-fished reserves than adjacent and distant fished areas across all years (non-fished: 4–28, fished: 3–34 ind/250 m^2), and varied between areas at the other reserves over time. Density of fish species in the middle of the food chain was similar between sites (non-fished: 0–148, fished: 0–151 ind/250 m^2). For the dominant fish group at the bottom of the food chain *Pomatocentridae*, density was higher in non-fished areas than fished for two reserves, one with good enforcement (non-fished: 7–149, fished: 0–70 ind/250 m^2), and density did not differ between areas at the other three reserves. In addition, the response to no fishing varied between individual fish families and abundances of larger and/or targeted fish by fishers was generally higher inside the reserves, while non-preferred species were more abundant outside. Data was collected at five no-fishing reserves in the Bohol Strait, differing in size (11–50 ha), age (established 1995–1999) and history of enforcement and compliance. One site inside and one outside (within 1,000 m) each of the reserves and at three distant fished sites were monitored twice a year in February-May and August-November from 1998-2004. Fish were surveyed by underwater visual censuses along four 50 x 5 m transects at each site. Fish were counted, fish length measured, and identified to species family and food chain group.

A replicated, site comparison study in 2001–2005 of four coral reefs on Abrolhos Bank, South Atlantic Ocean, Brazil (24) found that prohibiting all fishing in two no-take reserves, protected from 0 and 18 years, resulted in higher biomass of commercially targeted and non–targeted fish at the older reserve compared to multiple use protected areas and unprotected openly fished areas, but the response varied with fish species and/or level in the food chain. Across all years, total biomass of both commercially targeted and non-target fish groups was higher in the older no-take reserve than any other area, but openly fished areas had higher biomass than the younger and multiple use reserves (data reported as statistical results). However, the response varied by fish species and/or food chain group (see paper for individual data). Reef fish were monitored annually in January-March 2001–2005 in four areas: one reserve area in the Abrolhos National Marine Park (no-take since 1983); one no-take reserve (since November 2001) and one multiple-use area (co-managed since 2000, use permitted by locals only, zoning and gear restrictions) in the Corumbau Marine Extractive Reserve, and an unprotected fished, open access area. Some illegal poaching was reported in the no–take areas. Two habitats at three to seven sites were sampled in each management area by underwater visual census (15–20 samples/habitat/site/year). Fish were identified and counted in a 2 m or 4 m radius.

A replicated, site comparison study in 1992–2004 of 12 coral reefs in the Indian Ocean, off Kenya (25) found that grazing rates of fish on seagrass *Thalassia hemprichii* over a 12-year period were higher in no-take marine protected areas established for one and 24 years and where all fishing is prohibited, compared to fished reefs. For two different measures of fish grazing, both the rate of fish bites on seagrass (unfished: 53%, fished: 1%) and the average amount of algae eaten by fish at the unfished reefs (unfished: 65 kg/ha/d, fished: 2 kg/ha/d) were higher than fished reefs. In addition, coral cover in the unfished reefs (29%) was higher compared to the fished areas (16%). Fish grazing was monitored annually by two methods, at five sites in three marine protected areas: Malindi and Watamu (all fishing prohibited since 1968) and Mombasa (no-take since 1991); and seven sites in heavily fished areas. Firstly, thirty, 10-cm long blades of seagrass were soaked for 24 hours at each site and the numbers bitten by finfish recorded. Secondly, the biomass of selected fish herbivores along three to five, 500 m^2 belt transects at each site was used to estimate the amount of algal biomass eaten per day (based on 16% of body weight) per wet weight of fish.

A systematic review of unpublished data from 11 studies of five marine reserves surveyed between 1992–2002 in the southwestern Pacific Ocean around New Zealand (26) found that overall, blue cod *Parapercis colias* were found to be larger and more abundant in reserves where all fishing had been prohibited between 1 to 27 years, compared to fished areas outside. In nine of 10 cases, blue cod total length was greater inside unfished reserves (25–31 cm) than outside (20–27 cm) and for eight of 11 cases, cod were more abundant inside (0.003–0.099 fish/m^2) than outside (0.003–0.051 fish/m^2) unfished reserves. In addition, although the magnitude of the differences varied between reserves, blue cod length and abundance was not affected by the size or age of the reserves. A meta-analysis of 11 unpublished blue cod datasets from surveys of five no-take marine reserves was done. The reserves ranged in size from 93–2,400 ha and in age since protection from 1–27 years and prohibited all types of fishing. Blue cod length and abundance inside each reserve was compared to adjacent areas outside (distances apart were not reported).

A site comparison study in 1992–2005 of three rocky areas in the northwest Mediterranean off the coast of Spain (27) found that banning all types of fishing for at least nine years in a marine protected area resulted in higher biomass of white seabream *Diplodus sargus* and gilthead bream *Sparus aurata*, compared to nearby recreationally fished only and unprotected fished areas. Across all years, the average biomasses of white and gilthead bream were higher in the unfished area (white: 19.1 g/m^2, gilthead: 0.8 g/m^2) than the other areas, and were similar between partially fished (white: 5.9 g/m^2, gilthead: 0.1 g/m^2) and fished areas (white: 6.1 g/m^2, gilthead: 0.2 g/m^2). Fish were sampled annually from 1992–2005 at three nearby sites, up to 2 km apart: a no-take reserve in the Medes Islands Marine Protected area (no extractive activities, since 1983); a partial reserve (angling permitted but no collection of subtidal animals since 1990); and a fished stretch of coastline. Numbers of fish at each site were recorded by underwater visual transects (no further sampling details were reported).

A site comparison study in 2005–2007 of one coastal site in the Mediterranean Sea, France (28, same experimental set-up as 34) found that prohibiting all fishing activity in a marine protected reserve increased total fish biomass, abundance and species richness compared to outside the reserve where fishing is allowed, one to four years after protection. Average total biomass, abundance, and species richness was higher at one of two sampling sites inside the reserve in 2006 and at both in 2007 (biomass, 2006: 3 kg, 2007: 6–10 kg; abundance, 2006: 6, 2007: 9–10; species richness, 2006: 3.5, 2007: 7) compared to sites outside the reserve (biomass, 2006: <1 kg, 2007: <1–2 kg; abundance, 2006: 1, 2007: 1–4; species richness, 2006: 1, 2007: 1–4). In addition, the commercial fish assemblage was different inside and outside the reserve in 2006 and 2007 but not in 2005, and no differences were found for assemblages of small-sized fish over seagrass *Posidonia oceanica* seabed. Fish were monitored inside and at two locations outside (adjacent areas north and south) the Cape Roux Marine Protected Area (450 ha, all fishing types prohibited since December 2003). In October 2006 and June 2007, six trammel net deployments sampled all fish at two sites inside the reserve and one in each location outside. From 2005–2007, at total of 28 commercial (sampled every season for 2.5 years) and 28 small fish species (sampled in spring for one year) were surveyed by underwater visual census six to 10 times at two sites in each location.

A site comparison study in 2005–2007 of one no-take coral reef marine reserve, closed to fishing for 15 years, and two unprotected (fished) reefs in the Pacific Ocean off New Caledonia, France (29) reported that the tracked movements of four of four commercially important reef fish species indicated that most did not move from the unfished reef to the fished reefs and thus were largely protected from fishing, however, some fish did make large-scale movements outside of the reserve reef. Data were not tested for statistical significance. Of 45 fish tracked, a total of 36 (80%) did not move between the three reef sites but nine fish (20%), including at least one individual from each of the four species, moved distances of 510–6,000 m outside the reserve reef. The South Lagoon Marine Park was created in 1990 and has one temporary and nine permanent no-take marine reserves where all fishing is prohibited. From July 2005 to January 2007, movement data for 45 fish of four major commercial reef species (19 individuals of two *Serranidae* spp. and 26 individuals of two *Scaridae* spp.) fitted with transmitters were collected by 23 hydrophones deployed at 4–13 m depth around one reserve and two fished reefs. After being fitted with transmitters, 35 fish were released at their original site of capture (28 in the reserve and 7 in a fished reef) and ten fish that were caught in a fished reef were released inside the reserve. The number of days each fish was detected for was reported only for some individuals.

A site comparison study in 2000–2004 of an area of reef in the Indian Ocean, off South Africa (30) found that prohibiting all types of fishing in a marine protected area for over 10 years resulted in a different fish community, higher diversity and a higher abundance of four of the eight most common fish species compared to an adjacent fished reef. Fish community composition was found to differ between unfished and fished areas using both sampling methods and diversity was higher in the unfished area for the visual census survey only (unfished: 1.7, fished: 1.5). For both sampling methods, frequencies of roman *Chrysoblephus laticeps*, steentjie *Spondyliosoma emarginatum*, dreamfish *Sarpa salpa* and blacktail *Diplodus sargus capensis* were higher in the unfished area (unfished: 8–55%, fished: 5–36%) and fransmadam *Boopsoidea inornata*, blue hottentot *Pachymetopon aeneum*, santer *Cheimerius nufar* and dageraad *Chrysoblephus cristiceps* were lower (unfished: <1–14%, fished: <1–42%; see paper for species individual data by method). Fish were sampled inside and outside the Goukamma Marine Protected Area (40 km^2, all fishing prohibited since 1990) using two methods: standardised angling (111 sites inside, 162 outside) and underwater visual census (15 inside, 29 outside 44 sites). Angling surveys were carried out in all seasons from 2000 to 2003 by a team of 3–5 anglers. Seasonally in 2001–2004, fish were counted by divers in an area of up to 5 m radius.

A site comparison study in 2002–2003 at six reef sites in the southwestern Atlantic Ocean, off Puerto Rico (31) found that prohibiting all fishing in a marine protected area for three years resulted in similar abundances of red hind grouper *Epinephelus guttatus* and its associated prey fish species, and larger red hind size but similar growth and survival, compared to adjacent fished areas. There were no differences in red hind density (unfished: 9–23, fished: 6–26 fish/ha), growth rate or average annual survival rate between management types, but average total length was larger inside the unfished area (data reported as statistical results). Average abundances of three fish species and six family groups that are prey for red hind were similar between areas (unfished: 0–44, fished: 0–46 fish/no. census; see paper for species individual data). Red hinds and the prey fish community were surveyed at three sites inside the Luis Peña Channel Marine Fishery Reserve (4.75 km^2, established as no-take in September 1999) and three sites in adjacent fished areas outside. Fish abundance was recorded for all species by 16–23 underwater stationary visual censuses per site (sampling times were not reported). Red hind size and survival data was recorded for a total of 75 individuals from October 2002 to December 2003 by a tagging study totalling 60 fishing events (one/site/month).

A site comparison study in 2004–2005 at three island coral reef sites in the Indian Ocean, off Tanzania (32) found that a small marine protected area where all fishing had been prohibited for 13 years had a greater fish biomass compared to areas that have no fishing restrictions. Fish biomass was greater in the area that prohibited fishing (886 kg/ha) than two nearby areas where fishing is allowed (283 and 291 kg/ha). The privately owned Chumbe Island Coral Park off Zanzibar was established in 1991 (0.3 km^2, all extractive activities prohibited). In 2004–2005, fish were surveyed by underwater visual census (5 × 100 m belt transects) at two sites inside the protected area and two fished sites with no management 20 km away. Fish >3 cm were recorded by family group and 10 cm size categories, and biomass estimated from length–weight relationships.

A before-and-after, site comparison study in 1993–2001 of an area of coral reef in the southwest Pacific Ocean, off New Caledonia (33) found that over a nine year period, a marine reserve closed consecutively to all fishing for 5 years had higher overall fish species richness, but not fish abundance and biomass, compared to an area with changing fishing restrictions (initially closed, then opened for two years, then closed again) during the same period. Average fish species richness varied between years but was greater overall in the permanent closure area (permanent: 21–24, non-permanent: 19–21). Overall fish abundance and biomass declined over time in both the permanent (abundance, 1993: 201, 2001: 133 fish/transect; biomass, 1993: 45, 2001: 13 kg/transect) and non-permanent closure areas (abundance, 1993: 220, 2001: 163 fish/transect; biomass, 1993: 27, 2001: 15 kg/transect) but no effect of changes in area management were detected. However, differences between areas were reported for fish species groups divided up by size, feeding habit, mobility, and interest to fisheries (see paper for group individual results). Fish were surveyed at the Aboré reef reserve (15,000 ha, all fishing prohibited in the entire reserve in August 1988) in two areas with different management regime histories: one third closed to fishing since 1998, and two thirds closed in 1988, opened from September 1993 and closed again in September 1995. Diver underwater visual surveys were done in July 1993 (60 transects across entire closure area), July 1995 (48 transects in closed and 62 in open areas) and 2001 (42 transects across entire closure). Transects were 50 m long and fish were recorded by species and size.

A replicated, site comparison study in 2006–2007 in six areas of seagrass *Posidonia oceanica* bed in the Mediterranean Sea, France (34, same experimental set-up as 28) found higher abundance of some fish groups and higher species richness inside a marine protected area in which all fishing was banned compared to two fished reference areas, three years after designation. In May 2007, total biomass, species richness, total fish density and density of four fish families were similar during visual transects over seagrass beds inside and outside the reserve. In September 2007, total biomass, species richness, total fish density and that of two of four families were similar inside and outside the reserve, but density of breams *Sparidae* spp. and groupers *Serranidae* spp. were higher inside (bream: 9, grouper: 1/40 m^2) than outside the reserve (bream: 5–10, grouper: 0–1/40 m^2). Experimental netting data showed higher total abundance, abundance of scorpionfish *Scorpaenidae* spp. and species richness inside the reserve than outside the reserve in October 2006 (total: 4–9, scorpionfish: 1–3, richness: 3–5/100 m) and June 2007 (total: 1–2, scorpionfish: 0–1, richness: 1–2/100 m). The Cap-Roux Marine Protected Area (450 ha) was closed to all fishing in 2003. Two stations were sampled in each of three zones, one inside the reserve and two outside (north and south) of the reserve boundaries. At each station six replicate underwater visual censuses over seagrass beds and six 100 m trammel net deployments were undertaken. Sampling was undertaken seasonally from 2005–2007. Only data from 2006 were included in the analysis. For full sampling details see original study.

A site comparison study in 2003–2005 of an area of rocky seabed in the north-western Mediterranean Sea, off Spain (35) found that fish (functional) diversity and catch rates in local traditional fisheries were greatest closer to a marine reserve closed to all fishing for 22 years, and decreased with increasing distance from the reserve. Functional diversity (the roles played by different species in the ecosystem) and fisher catch rates increased with decreasing distance from the reserve (data reported as statistical model results). However, these were also strongly affected by the presence of a seagrass bed along the western border of the reserve buffer zone. Species diversity was also highest in the waters surrounding the area protected from fishing compared to further away and changed with depth (data reported graphically). In addition, the value of catches were highest within the buffer zone of the reserve. Data were collected between March and December from 2003–2005 in two areas: the buffer zone (418 ha, only artisanal fishing allowed) surrounding the Medes Islands marine reserve (93 ha, designated in 1983, all fishing banned inside the reserve in 1991), and in the adjacent unprotected fished area up to 9 km away from the buffer zone. A total of 44 trammel net fishing operations were sampled and 1,685 fish were counted, identified and fish length recorded.

A site comparison study in 2004 of the water column around an island in the Mediterranean Sea off Mallorca, Spain (36) found that there were more eggs of four commercially targeted fish species inside a no-take (no fishing) marine reserve enforced for three years and in which the adult fish were more abundant, compared to outside (thus protecting a spawning area from fishing and increasing the likelihood of successful egg production). The eggs of all four species/groups (scorpion fish *Scorpaena* spp., Mediterranean rainbow wrasse *Coris julis,* brown meagre *Sciaena umbra* and grouper *Epinephelus* spp.) were distributed in higher densities inside the non-fished reserve compared to locations outside, up to two nautical miles away (data reported as statistical results and presented graphically). In addition, there was a clear gradient of decreasing egg density with distance away from the reserve for wrasse and grouper. Plankton was collected in July 2004 inside and outside the marine section of the Cabrera National Park (87 km^2, designated 1991, enforced 2001) by two methods: bongo nets (27 stations inside and outside, repeated four times) and fixed nets (9 stations inside). Bongo nets were deployed in down and up oblique tows between the surface and 10 m off the seabed (down) and horizontally for five minutes at 20, 10 and 2 m depths (up). Fish eggs (sub-sampled over 200) were identified and counted in the laboratory under a microscope.

A replicated, site comparison study in 1992–2006 of nine coral reef sites in the Indian Ocean, Kenya (37) found that the effects of closing protected areas to all fishing for over 15 years on fish abundance varied between species, compared to adjacent openly fished areas, and the effects on fish species richness and diversity varied with the method used to assess them (fisheries independent underwater visual census versus fisheries dependent catch data). Across bot sampling methods, fish abundances differed between non-fished and fished areas, with about half of the species recorded as common to both management areas by each method being more abundant in closed areas (data reported graphically and as statistical results). Visual census sampling found that the total number of fish species was higher in closed (134) than fished areas (94) and species diversity was similar (0.94–0.95). In contrast, trap and line fishing methods found lower numbers of fish species and diversity at closed areas (number, closed: 30–79, fished: 73–107 species; diversity, closed: 0.5–0.8, fished: 0.8). Trap and line fishing data was collected from two fisheries dependent sources: experimental catch and release studies undertaken for scientific purposes in three old Kenyan fisheries closures (established by 1978, all extractive activities prohibited) and catch composition measured from adjacent traditional fisheries using the same gear types at six heavily fished grounds; and compared with existing fisheries dependent data (underwater visual census surveys, see paper for studies) collected at the same sites. Experimental fishing took place between 1995 and 2006 at three closed areas: Malindi and Watamu Marine National Parks (traps only) and Kisite Marine National Park (traps and line); and six fishing grounds (both methods, line catches obtained from local traditional fishers). Visual census surveys were done at all sites between 1992–2006 (see original paper for details).

A replicated, site-comparison study in 2005 of shallow rocky reefs in three marine protected areas established for 9–15 years in the Atlantic Ocean around the Canary Islands, Spain (38) found that banning all types of fishing resulted in a different fish assemblage and increased abundance of grey triggerfish *Balistes capriscus* and barred hogfish *Bodianus scrofa* compared to unprotected (fished) reference areas, but abundance of ocean triggerfish *Canthidermis sufflamen* and ornate wrasse *Thalassamo parvo* was similar. Across all three islands, the fish assemblage was different in unfished and fished areas. Average abundance of grey triggerfish and barred hogfish was higher in the unfished areas (triggerfish: 0.3–0.6; hogfish: 0.1–0.4 fish/100 m^2) than the fished areas (triggerfish: 0.0–0.2; hogfish: 0.0 fish/100 m^2). Similar abundance in unfished and fished areas was recorded for ocean triggerfish (0.0–0.2 vs 0.1 fish/100m^2) and ornate wrasse >12 cm (22.3–35.0 vs 21.7–31.2 fish/100m^2). Also reported, but not statistically tested, was abundance of zebra seabream *Diplodus cervinus* >30 cm (unfished: 0.7-1.3; fished: 0.2–0.6 fish/100m^2) and white seabream *Diplodus sargus* >30 cm (unfished: 0.2–0.7; fished: 0.1–1.0 fish/100m^2). Fish surveys were done in April-November 2005 at four sites in each of three marine protected areas and three nearby unprotected fished areas. Protected areas were designated 9–15 years prior, prohibited all fishing. At each site, divers recorded the number and length of all fish for 5 minutes within a 100 m^2 circle at six replicate locations.

A systematic review in 2011 of 32 studies of marine reserves in the Atlantic and Pacific Oceans off Latin America and the Caribbean (39) found higher total (fish and invertebrates) density, biomass and body size, but not species richness, inside protected areas where fishing is prohibited compared to unprotected fished areas, and the response of fish species was greater than other groups. Data were reported as response ratios. At the food chain level, the increase in density and biomass of fish predators in no fishing reserves was greater than herbivores (fish and invertebrates combined), macroalgae and corals, and at the species level, the increase in density of fish species was greater than invertebrate species. In addition, there was no relationship between the size or age of reserves or area surveyed and the species density (fish and invertebrates) response, but it was found to be associated with one of four variables, intensity of exploitation outside the reserve (i.e. the higher the exploitation level the greater the species response). The systematic review summarized the effects of protection from fishing activities at 23 marine reserves established from 1959 to 2001 in Latin American and Caribbean countries. Four publication databases were searched from 1970–2007 and fifteen site comparison and five before-and-after site comparison studies selected. Data from inside and outside the reserves and before and after designation were used to calculate response ratios to represent the size of the effect of protection.

A replicated, site comparison study in 2005–2006 of 20 reef sites in the Indian Ocean off Kenya and the Maldives (40) found that prohibiting all fishing in protected areas (Kenya) for over 25 years resulted in higher total fish biomass, density and species richness compared to heavily fished unprotected areas, but not to partially fished management areas (Maldives). Total biomass in the fully closed areas (1,180 kg/ha) was similar to partially fished areas (1,463 kg/ha), and both were higher than fished areas (110 kg/ha). For nine fish family groups, total density differed between all three areas and was highest at partially fished areas (closed: 463, partly fished: 602, fished: 202 fish/500m^2); and species richness was similar at closed and partly fished areas and higher than fished (closed: 45, partly fished: 45, fished: 26 species/500m^2). In addition, the effects of different management regimes varied for individual family groups (see paper for data). Fish were surveyed by underwater visual census in four well enforced marine protected areas in Kenya (total 54 km^2, established in the 1970s, all fishing prohibited) and four nearby heavily fished areas; and in the Maldives, at 12 sites in a large, lightly managed fished area (650 km^2, selectively fished, non-enforced closure system). Sampling took place in February to May 2006 (Kenya) and June 2005 (Maldives). Fish biomass for 23 families was sampled by one or two separate passes along four 5 × 100 m belt transects/site and data for nine selected families by four passes along the 500m^2 transects.

A replicated, site-comparison study in 1996–2009 at eight coral reef sites in the Caribbean Sea, off Belize (41) found that over a 15 year period following closure of an area of a marine reserve to all fishing, there was a higher number reef fish species and higher abundance of some species groups compared to nearby fished reefs in the reserve, and the effect varied with level in the food chain. The total number of species was higher at unfished reefs (19–27) than fished reefs (17–20) and increased with time. Seven of 17 fish family groups were more abundant (individuals observed/5 min) inside than outside the reserve, nine were similar, and one (*Pomacentridae*) was more abundant outside (see paper for individual data by group). Snapper abundance (*Lutjanidae*) showed the largest increase inside the reserve over time (13–72), whilst remaining constant outside (7). Average abundance of carnivorous fish was higher inside than outside the reserve, including: fish-eating fish (16 vs 4); fish that feed on large invertebrates (2 vs 1) and fish that feed on small invertebrates (159 vs 126). Abundance of herbivorous fish (284 vs 298) and sponge-eating fish (1 vs 1) was similar inside and outside the reserve. Fish were surveyed by underwater visual censuses at four reefs in the conservation zone (71 km^2, legal protection in 1993, no fishing since 1995) and four nearby reefs in the general use zone (190 km^2, regulated fishing activity) of Glover's Reef Marine Reserve. Each reef site was sampled 8–10 times during May-November between 1996–2009. Divers haphazardly swam over each reef for a total of 35 minutes and recorded the number and species of fish from seven taxonomic groups during separate 5-minute intervals.

A replicated, paired, site comparison study in 2009–2010 of four estuaries in the Tasman Sea, New South Wales, Australia (42) found higher average abundance of commercially targeted fish and similar species number in marine park zones where all fishing has been prohibited for four to eight years, compared to partially fished park zones, but there was a lower abundance of targeted fish and a different overall fish assemblage than unprotected fished estuaries. Abundance in no fishing park zones was higher than fished park zones for all targeted fish (no fishing: 3.9, fished: 1.5 count/camera drop), and individually for pink snapper *Pagrus auratus* (no fishing: 0.9, fished: 0.1 count/camera drop), but was similar for silver trevally *Pseudocaranx georgianus* and yellowfin bream *Acanthopagrus australis* (trevally: 1.0 vs 0.0, bream: 0.2 vs 0.1). The number of fish species (no fishing: 6.3, fished: 4.8) and maximum abundance of all fish (no fishing: 27, fished: 45 fish/camera drop) were similar in non-fished and fished park zones. In addition, targeted fish abundance was higher in estuaries without marine parks (12 fish/camera drop) and had a different fish assemblage (data reported graphically). Four estuaries, in New South Wales (100–400 km apart) were randomly sampled from November 2009 to March 2010 using baited remote underwater video. Two estuaries were marine parks (four and eight years old), zoned into no fishing areas and areas where some commercial and recreational fishing (netting and trapping) was permitted. The other two estuaries had no conservation designation and although most commercial fishing was banned they were intensively fished recreationally.

A replicated, site comparison study in 2005 of seven coral reef areas in the Indian Ocean off the coasts of South Africa and Mozambique (43) found that six years after prohibiting all fishing in no-take areas of marine reserves there was increased abundance of six of 12 fish species/groups compared to partly fished and openly fished areas, and overall fish size was larger than in openly fished areas. Average abundances were higher inside no-take areas than partly fished and openly fished areas for six of 12 fish species/groups (no-take: 0.5–9.0 fish/count, part fished: 0.1–3.0 fish/count, open: 0.0–3.0 fish/count). The abundances of the other six were higher in no-take areas compared to partly fished but were similar to openly fished areas (no-take: 0.3–10.0 fish/count, part fished: 0.0–6.0 fish/count, open: 0.3–10.0 fish/count). See original paper for list of species and individual abundances. Average fish size (reported as a standardised measure) across the whole assemblage was higher inside no-take areas (57) than openly fished areas (48) and similar to partly fished areas (58). In April 2005, fish were sampled at two no-take areas (no extractive activity) and four partly protected areas (limited non-commercial/non-trawl fishing types and diving permitted) in adjacent marine reserves (designated 1999), and at five openly fished sites outside the reserves (two adjacent and three >200 km away). At each site, divers counted selected fish species >7 cm in length, along two replicates of bisecting transect pairs 25 m long and 5m wide. Point counts (22–32) were also conducted at each site in a 5 m radius, separated by 20 m. Data were analysed for seven coral-dominated sites (two no-take and open, three part protected).

A replicated, paired, site comparison study in 2004–2010 of five coral reef regions in the Great Barrier Reef Marine Reserve, Australia (44) found that reefs closed to fishing for two to six years had greater numbers of coral trout *Plectropomus/Variola* spp., compared to fished reefs. Across all years and reef regions, the total number of coral trout was greater at reefs closed to fishing (0.8–0.9 fish/tow) than open reefs (0.4–0.6 fish/tow). Similarly, overall coral trout number at each of the five individual reef regions was higher at sites closed to fishing (Cairns: 0.2–0.3 fish/tow; Townsville: 0.5–0.7; Mackay: 1–1.1; Swains: 1.4–2.6; Capricorn Bunker: 0.5–0.8) compared to their paired, fished sites (Cairns: 0.1–0.2 fish/tow; Townsville: 0.1–0.2; Mackay: 0.1–0.5; Swains: 0.2–1.3; Capricorn Bunker: 0.2–0.4). In 2004, the Great Barrier Reef was rezoned to create no-take marine reserves. In 2006–2010, a total of 28 pairs of reefs were surveyed across five reef regions, 25–450 km apart (six pairs in each region except Capricorn Bunker, where four pairs were surveyed). Each reef pair was one reef closed to fishing and one fished (0-1 km apart). Fish at each reef site were sampled by the manta tow method, where 10 m-wide areas of reef slope are surveyed at a time by an observer towed behind a small boat, for two minutes. Paired sites were surveyed within 12 months of each other on a biennial basis over six years.

A site comparison study in 2009–2010 at seven mangrove and coral reef sites in Moreton Bay, Coral Sea, Australia (45) found that prohibiting all fishing inside a marine reserve for over 12 years resulted in greater fish density of three of four fish groups at coral reefs and one of four in mangroves, compared to non-reserve areas, and was influenced by proximity to other habitat types. At no-take coral reef areas close to mangroves, fish density of three of four fish groups was higher than non-reserve areas (harvested: 65–159 vs 42–96, herbivorous: 75–138 vs 34–79, piscivorous: 22–39 vs 13–26 fish/200 m^2), but the density of prey fish species was lower (reserve: 77, non-reserve: 145 fish/200 m^2). Reserve coral reef areas far from mangroves had greater fish density for piscivorous fish only compared to non-reserve areas (28–30 vs 19–22 fish/200 m^2). Mangroves in reserve areas near coral reefs had greater densities of piscivorous fish (reserve: 37, non-reserve: 18 fish/200 m^2) but lower densities of prey fish (reserve: 41, non-reserve: 255 fish/200 m^2). Reef fish were surveyed in summer 2009–2010 inside a no-take marine reserve, protected since 1997, and at six non-reserve sites in Morton Bay (0–25 km away). At each site, two coral and three mangrove areas were sampled. On coral reef, fish were sampled along five, 50 by 4 m transects at each site by underwater visual census. Fish in mangroves were surveyed at high tide using underwater transects and fyke nets.

A replicated, site-comparison study in 2009–2011 at five coral reefs in the Coral Sea, Australia (46) found that prohibiting all fishing within a no-take marine reserve for over 12 years increased the diversity and biomass of herbivorous fish compared to non-reserve reference areas at reefs close to, but not distant from, mangrove forests. At reefs close to mangroves, herbivore species richness was higher inside the reserve (8 species/200 m^2) than outside (5 species/200 m^2), but similar for reefs further away from mangroves (inside: 5, outside: 4 species/200 m^2). Herbivore biomass at reefs close to mangroves was also higher inside the reserve (inside: 14, outside: 7 g/m^2), mainly due to the higher biomass of roving browsers and black rabbitfish *Siganus fuscescens* (data reported as statistical model results), and similar at distant reefs (inside: 3, outside: 2 g/m^2). In addition, across both near and far reefs the biomass of roving grazers, the Australian sawtail *Prionirus microlepidotus* and the blue-barred parrotfish *Scarus ghobban* was higher at reserve than non-reserve reefs (data reported as statistical model results). Fish were surveyed along five replicate 50 × 4 m underwater transects at low tide at one protected reef and four unprotected reefs in the Moreton Bay Marine Park, eastern Australia, from November 2009 to January 2011. The protected reef is a no-take reserve where all fishing is banned (since 1997). At each location one reef close (<250 m) to mangroves and one distant (>500 m) from mangroves were sampled.

A replicated, paired, site comparison study (year not stated) of three marine reserves in the Mediterranean Sea, Spain (47) found that prohibiting all fishing resulted in higher biomass of predatory, but similar biomass of herbivorous, fish inside one no-take marine reserve compared to outside unprotected areas, and similar biomass to two other marine reserves with a different level of protection from fishing. The total biomass of predatory fish was higher inside than outside (inside: 32,522, outside: 13,984 g/250m^2) at the only no-take reserve (Catalunya) and was similar at the two other reserves (inside: 10,025–15,699, outside: 6,484–18,815 g/250m^2). No effect of protection level was found on the total biomass of herbivorous fish at all three reserves (inside: 5,322–15,000, outside: 3,064–4,516), but it was influenced by an interaction of protection, depth and reserve region (data reported as statistical results). At each reserve, three sites were sampled inside and three outside the reserve boundaries, one at each depth of 5, 15 and 30 m (date or year of sampling unspecified). Fish were identified and counted by diver underwater visual survey along three, 50 × 5 m transects at each site. Herbivorous fish and fish that predate on sea urchins *Paracentrotus lividus* were recorded (see paper for list of families). The Catalunya reserve was protected since 1983 and prohibits all extractive activities. The other two reserves were protected since 1991 (Mallorca) and 1999 (Menorca) and permit some restricted commercial fishing.

A replicated, paired, site comparison study in 2008 of five shallow rocky seabed areas in the Mediterranean Sea, Spain (48) found that no-take marine reserves closed to fishing for at least 10 years, had higher overall abundances of top predators (fish) and carnivore species (fish and invertebrates) and a similar abundance of herbivore species (fish and invertebrates), compared to non-protected areas outside. Overall, top fish predators (two families) and carnivores (three fish families, one invertebrate) were more abundant inside than outside the no-take marine reserves and the abundance of herbivores (one fish and one invertebrate species) was similar (data reported as statistical results and presented graphically for each reserve). In August 2008, five marine reserves along the east coast of Spain were surveyed by underwater visual census. Six transects, 50 × 5 m, were done at each reserve: three in no-take areas and three in unprotected areas nearby (4–12 km). All fish, and two invertebrate species, were identified, counted, and assigned to one of three universal feeding groups (see paper for list of species). Reserves were protected for 10–25 years.

A replicated, site comparison study in 2010–2011 at six coral reef sites in a marine park in the Indian Ocean, Western Australia (49) found that the level of protection from fishing did not influence fish abundance, biomass and diversity between zones where no fishing was permitted for five to 20 years and fished zones. Total fish abundance, biomass and diversity of adult fish was similar between unfished and fished zones (data presented as fitted model outputs and statistical results), but some differences were found for fish grouped together based on diet/feeding behaviour (see paper for results by fish group). Sanctuary zones (free from fishing) in Ningaloo Marine Park were established in 1991 and 2005. At each of six sites within the reserve; three where no fishing is allowed, and three where some commercial fishing is permitted, a total of 9–14 patch reefs 2–4 m deep were surveyed. All adult fish visible on each reef were identified and counted by a single underwater observer in November 2010–January 2011.

A before-and-after, site comparison study in 1996–2005 of three seabed areas on the Patagonian Shelf, South Atlantic Ocean, off Argentina (50) found a different assemblage of bottom dwelling fish, higher overall abundance and higher abundance of target Argentinian hake *Merluccius hubbsi*, and particularly of young hake, in a marine protected area in which fishing was banned for up to eight years, compared to two fished reference areas. The whole fish assemblage before the closure was similar in the protected area to one of the two outside areas but differed from both outside areas after the closure (data reported as statistical model results). Before the closure, overall fish abundance was similar inside (0.59 t) and outside (0.45–0.79 t) the reserve, but increased inside the reserve following the closure and was higher than outside in two of four years (inside: 0.73–0.88, outside: 0.27–0.54 t). Hake abundance was similar across areas before the closure (inside: 0.54, outside: 0.26–64 t) but increased inside the reserve and was higher after the closure in all years (0.52–0.89 t) relative to outside (0.13–0.61 t). The proportion of two-year old hake inside the reserve was higher after the closure (36–50%) than before (18%). The Patagonian Closed Area (50–100 m depth) was closed to all fishing in 1997. Data from demersal fish surveys (5 × 30 m trawl with a 2.4 cm codend mesh) before (1996) and after (2000–2003, 2005) the closure were analysed from a selected 28,000 km^2 area inside the reserve and two fished areas outside. All fish were counted, identified, and the ages and lengths of hake recorded.

A replicated, before-and-after, site comparison study in 1999–2011 at four coral reef sites in the Gulf of Mexico, off Florida Keys, USA (51) found that in marine reserve areas where all fishing was prohibited for up to 10 years, and in areas where only recreational fishing is permitted, there were increases in the density of commercial fish species in the 10 years following implementation and compared to openly fished areas, and changes in fish densities of non-target and other exploited fish species varied. For five fishery exploited species, the total number of increases in density detected in surveys was higher overall in no-take and recreationally fished areas compared to openly fished areas (no-take: 3, recreational: 16, fished: 1), and decreases were only detected in the openly fished areas (no-take: 0, recreational: 0, fished: 5). For non-target species (increase, no-take: 9, recreational: 20, fished: 12; decrease, no-take: 9, recreational: 12, fished: 3) and species collected for the aquaria trade (increase, no-take: 0, recreational: 7, fished: 1; decrease, no-take: 9, recreational: 7, fished: 3), changes in density fluctuated between years (see paper for species individual data). Fish were surveyed over 326 km^2 at four sites with three different levels of resource management protection; Tortugas North and South Ecological Reserves (no-take, since 2001), Dry Tortugas National Park (part no-take, since 2007 and part recreational angling only, since 1960s in all areas). Baseline fish surveys were done in 1999–2000 before the no-take areas were implemented and from 2002–2011. Diver visual surveys were done in a two-stage stratified random sampling design. Numbers of reef fish were recorded in randomly selected circular plots 15 m in diameter.

A site comparison study in 2009–2010 of 12 rocky reef and boulder sites in the Mediterranean Sea, off eastern Sicily, Italy (52) found that five to six years after all fishing was banned in a reserve zone of a marine protected area, the overall fish assemblage was different and fish abundance, species richness and diversity was higher compared to fished areas outside the reserve, but the effect on individual species abundance varied between size classes and commercial/non-commercial species. The overall fish assemblage was different inside and outside the reserve (data reported as statistical results) and total fish abundance was higher inside (226 fish/125 m^2) than outside (90 fish/125 m^2). This was due to greater abundances of medium and large fish inside (medium: 80, large: 108 fish/125 m^2) than outside (medium: 38, large: 25/125 m^2), as well as species of high commercial value (24 vs 4 fish/125 m^2). Abundance of small and low and medium commercial value fish were not significantly different inside and outside the reserve (small: 38 vs 27 fish/125 m*2*, low value: 12 vs 8 fish/125 m^2, medium value 67 vs 4 fish/125 m^2). Fish species richness and Shannon diversity were higher inside the reserve (species: 14, diversity: 1.7 fish/125 m^2) than outside (species: 12, diversity: 1.5 fish/125 m^2). Fish were surveyed by underwater visual census in early summer 2009–2010 along three 125 m^2 transects (15–20 m depth) at four sites inside the marine reserve zone (where all fishing activities are prohibited since 2004) of the Plemmirio Marine Protected Area (2,400 ha), and eight sites outside the reserve (four in an adjacent zone where only some controlled fishing activities are allowed and four outside the marine protected area, 12 km away).

A site comparison study in 2006–2008 of a shallow, sandy lagoon in a bay in the South Atlantic Ocean, off South Africa (53) found that common smoothhound sharks *Mustelus mustelus* spent more time in a no-take marine protected area than outside (and thus more protected from fishing), and movements between the areas differed with season. Overall, sharks spent an average of 74–80% of hours inside the no-take area over a two-year period. The highest numbers of detections inside the no-take area occurred in summer and the lowest in winter (data presented graphically and as statistical results). In November 2006, a total of 24 smoothhound sharks were tagged with acoustic transmitters and released in the Langebaan Lagoon Marine Protected Area (34 km^2, year implemented not reported), a no-take area in the innermost part of a coastal embayment (Saldanha Bay). The movements of sixteen sharks (9 females, 7 males) detected for at least one year, and of nine detected for two years, were analysed. Fish movement detection data was recorded by 28 acoustic receivers positioned at four sites in no-take and fished areas.

A replicated, paired, site comparison study in 2004–2005 of coral reef and seagrass sites at three neighbouring inhabited islands in the Java Sea, Indonesia (54) found that prohibiting fishing in areas of a 16 year old national park resulted in similar individual fish size and weight in catches landed at two of the three islands, compared to fished areas. Average fish length and weight in landed catches were similar between closed and fished areas at the islands of Karimunjawa (length, closed: 235 mm, fished: 222 mm; weight, closed: 482 g, fished: 395 g) and Parang (length, closed: 317 mm, fished: 311 mm; weight, closed: 733 g, fished: 766 g) and were lower in closed areas at Nyamuk island (length, closed: 306 mm, open: 411 mm; weight, closed: 781 g, open: 1,040 g). Karimunjawa National Park (111,625 ha) was first legislated in 1988 and has zones prohibiting fishing and designated fishing zones. In January 2004–December 2005, fish catch surveys were done by trained observers at 1–2 month intervals at fish landing sites on Karimunjawa Island. A total of 8,674 fish from 895 fishing trips were sampled. Fishers were asked to provide details of where they were fishing and the location of fish capture was assigned to one of five village fishing grounds on separate islands 6–15 km apart. Fishing was reported from both closed and fished management zones off three islands and the fish data compared.

A replicated, paired, site comparison study in 2012 of six coral reef sites in a marine protected area in the Coral Sea, Vanuatu (55) found that permanent no-take reserves where fishing was prohibited for at least six years had greater total fish biomass compared to areas open to fishing, and similar fish biomass to closed areas fished only periodically for short periods. The total fish biomass was similar in no-take reserves (646–835 kg/ha) and periodically fished areas (559–567 kg/ha) but was greater than fished areas (331–378 kg/ha). The biomass and abundance (data not reported) of only one of three individual fish groups differed between areas and was higher in no-take reserves than the other two areas (see original paper for individual data). Data was collected in November–December 2012 in two regions of the Nguna-Pele Marine Protected Area Network. Each region had three adjacent management zones (8 to 16 ha) that were each surveyed: a no-take reserve (since 2005), a periodically fished area open for 1–3 days every 6 months (implemented since 18 months to 6 years) and an area open to fishing. At each zone before and after a three-day harvesting period of the periodically fished zone, divers recorded fish species and length along eight, 50 by 5 m transects, and biomass calculated from length-weight relationships.

A site comparison study in 2005–2010 of three coral reef areas in the Caribbean Sea off Puerto Rico (56) found that prohibiting all fishing in a marine protected area resulted in a similar coral reef fish abundance and biomass one and five years after implementation compared to fished areas, but abundance increased in all areas over time. Overall, there were no differences in average reef fish abundance and biomass between no-take and fished locations, but after 5 years abundance had increased in all areas, regardless of protection level, particularly for small life stages and small-sized fish (data presented graphically and as statistical results). A no-take zone at the Mona Island Marine Protected Area was established in 2004 extending up to 926 m from the shore initially and modified in 2007 to include areas up to 182 m depth. Two locations in the no-take area and one in a fished area of the marine protected area (within the 2004 boundaries) were surveyed in autumn and winter of 2005–2006 and 2009–2010. At each location, fish size and abundance were recorded by underwater visual census along 12 belt transects

(60 m^2) at three separate sampling sites. After each transect five-minute roving surveys were conducted.

A replicated, paired, site comparison study in 2011 of six mixed reef, mangrove and seagrass lagoon areas in the Soloman Sea, Soloman Islands (57) found that no-take marine reserves protected for eight years had higher fish abundances than unprotected fished sites for four of six species, but the effect differed with type and proximity of different habitats. Fish density of four of six species was higher in at least two of the five habitat categories in no-take reserves compared to fished areas (bumphead parrotfish *Bolbometopon muricatum*: 2–6 vs 0, mangrove snapper *Lutjanus argentimaculatus*: 4–5 vs 0–1, goldlined rabbitfish *Siganus lineatus*: 5–31 vs 0–5, ringtail surgeonfish *Acanthurus blochii*: 5–15 vs 1–3 fish/200 m^2). For two species, density was similar between areas in four of the habitats and was lower in reserves in one (monocle bream *Scolopsis* spp: 5 vs 8, dash-and-dot goatfish *Parapeneus barberinus*: 1 vs 7 fish/200 m^2). In addition, the authors reported increases in abundance in reserves of a total of 18 fish species (data presented in the Supporting Information). Three small, community-based no-take reserves (established eight years) designed for bumphead parrotfish, and three paired unprotected fished locations were surveyed in April-June 2011. At each location, fish over 5 cm length were recorded by underwater visual census (5 × 200 m^2 transects) in mangrove, seagrass and coral reef habitats. Fish data were assigned to one of five categories: mangroves near coral, coral near mangroves, isolated coral, coral near seagrass and seagrass near coral.

A site comparison study in 2010–2013 of a fished area of seabed in the north Atlantic Ocean off the Isle of Arran, Scotland, UK (58) found that prohibiting all types of fishing in a marine reserve resulted in similar overall fish abundance, similar abundances of seven of seven individual fish groups, and similar sizes of four of four fish groups compared to an adjacent fished area outside the reserve, up to five years after implementation. Across years, overall fish abundance (total number) was not statistically different between non-fished reserve and fished areas (reserve: 803, fished: 644) and the maximum numbers of seven of seven fish groups, dominated by cod *Gadus morhua* and other 'cod-like' fish *Gadidae*, were similar (reserve: <1–9, fished: <1–9; see paper for individual data by fish group). Fish size was similar between the reserve and fished areas for cod, other cod-like fish, flatfish *Pleuronectidae* and lesser-spotted dogfish *Scyliorhinus canicula* (data reported as statistical results; three fish groups were not tested). Lamlash Bay Marine Reserve (2.7 km^2) was established in September 2008 and closed to all fishing. Annually between 2010–2013, fourteen to 20 sites inside and outside the reserve were sampled. Fish data were collected by diver visual surveys along 150 m^2 transects (total number) and analysis of footage recorded by baited remote underwater video (species, number and fish length).

A replicated, site comparison study in 2009–2011 of 23 coral reef sites spanning four regions in the Pacific Ocean (Phillipines, Papua New Guinea, Vanuatu) and Indian Ocean (Chagos) (59) found that surgeonfish and parrotfish inside established marine protected areas where fishing was banned showed the same pattern of increasing avoidance behaviour (measured as flight initiation distance) with increasing fishing intensity in the locality, compared to fish in fished areas. Flight initiation distance increased in both non-fished and fished sites with increasing local fishing pressure levels (lowest to highest) for surgeonfish *Acanthuridae* spp. (from 155 to 222 cm in non-fished areas and 270 to 408 cm in fished) and parrotfish *Scaridae* spp. (from 211 to 279 cm in non-fished areas and 332 to 537 cm in fished). In 2009–2011 thirteen sites protected from fishing through permanent no-take reserves or traditional management closures (reserve size or year of implementation were not reported) and 10 sites that allowed fishing were surveyed across four countries. Fish flight initiation distance was estimated by measuring how closely a diver could approach individual fish (> 10 cm total length) before they fled. Fishing pressure was estimated by dividing the linear extent of reef open to fishing by the number of fishers in the fishing community and ranged from 0–80 fishers/km.

A replicated study in 2001–2013 of four surf-zone sites in the Indian Ocean, off South Africa (60) found that over a nine-year period, the majority of recaptures made of tagged fish from five species, occurred inside a marine reserve where fishing activity was controlled by zones, and mainly within 200 m of their original release site in the no-take reserve zone closed to all fishing for over 22 years (and thus spent more time in areas protected from fishing). Most individuals of the five main study species were recaptured within 200 m of their original release site (grey grunter *Pomadasys furcatus*: 88%, catface rockcod *Epinephelus andersoni*: 84%, yellowbelly rockcod *Epinephelus marginatus*: 92%, cave bass *Dinoperca petersi*: 88% and speckled snapper *Lutjanus rivulatus*: 79%) and 61% of fish were originally tagged at sites in the no-take zone, the rest in the zone that allows shore angling and recreational boat angling and spearfishing for pelagic gamefish only. In addition, the maximum time at liberty of each species ranged from 287–3,163 days, average recapture rate was 29% and 632 of the 3,224 fish tagged were recaptured at least once. The St Lucia Marine Reserve in South Africa was established in 1979. From November 2001–2013, a total of 6,613 fish from 71 species were tagged and released at four sites in the reserve: two in a no-take zone and two in a restricted fishing zone. Over the same sampling period, details of fish recaptured in the reserve by the research team and angling public, and other reported recaptures in fished areas outside the reserve were recorded.

A replicated, site comparison study in 2005–2012 of 233 coral reef sites across the western Indian Ocean (multiple countries) (61) found that the biomass of the fishable portion of reef fish communities (standing stock biomass) increased across a gradient of decreasing fishing intensity resulting from six different management regimes, and was highest in protected areas closed to fishing and with enforcement. Data were not statistically tested. Average fishable biomass was greatest in large, remote marine protected areas (2,189 kg/ha, 36 sites) and areas closed to fishing with high compliance (957 kg/ha, 114 sites), whereas young areas closed to fishing with low compliance had 489 kg/ha (66 sites). Areas where all (line and traps only) or most (spear and gill nets also used) destructive gears were restricted had 390 and 382 kg/ha of fishable biomass, respectively. The lowest biomass was in areas with no gear restrictions (269 kg/ha, 50 sites, seines and explosives used). In addition, many of the individual sites, even in areas with closures and high compliance, had a fishable biomass below 1,150 kg/ha (estimated by the authors as the target standing stock biomass needed for the recovery of exploited reef fish), and were thus failing to achieve conservation targets. Coral reef fish assemblages were surveyed at 233 individual sites across the Indian Ocean (off Comoros, Kenya, Madagascar, Mayotte, Mozambique, the Maldives, Seychelles, the Chagos archipelago and Tanzania) between 2005–2012. Fish were surveyed at each site by underwater visual census (3 to 5 belt transects of 50 or 100 m, or 8 point counts – see original paper for sampling methods by country). Sites were classified by the six dominant management categories.

A replicated, site comparison study in 2012–2013 of 37 coral reef sites with at least one established, locally-managed marine protected area in the Philippine Sea, Philippines

(62) found that areas where all fishing was prohibited had greater fish species richness and diversity, fish density and larger fish for five out of seven family groups, compared to nearby fished areas. Overall fish species richness and diversity (data reported as diversity indices) was higher in protected areas (20 species) than fished areas (15 species). Density was higher for five of seven reef fish families (surgeonfishes *Acanthuridae*: 18 vs 16, parrotfishes *Scaridae*: 9 vs 6, snappers *Lutjanidae*: 7 vs 6, groupers *Epinephelinae*: 3 vs 2, goatfishes *Mullidae*: 2 vs 1 fish/500 m^2) and similar for grunts *Haemulidae* and emperorfish *Lethrinidae* (both <1 fish/500m^2 in all areas). A greater number of larger (25 cm and above) individuals of five families were found at protected sites compared to fished sites (surgeonfishes: 0.8 vs 0.1, parrotfishes: 1.4 vs 0.4, groupers: 0.4 vs 0.2, goatfishes: 0.2 vs 0.1, grunts: 0.13 vs 0.07 fish/500 m^2) and similar for snappers (0.7 vs 0.6 fish/500m^2) and emperors (0.0 vs 0.0 fish/500m^2). Between 2012–2013, reef fish were surveyed at 37 locations by underwater visual census along 348 belt transects (50 × 10 m). At each location, 8–12 transects were done, half in and half outside (>200 m) protected areas. Species, number, and estimated length was recorded for fish above 5 cm. The marine protected areas were mostly <50 ha, and the years since implementation were not reported.

A site comparison study in 2011–2013 of 18 coral reef sites on the Great Barrier Reef in the Coral Sea, Australia (63) found that in a marine protected area where human activity was controlled by zones, of six different fish trophic groups, two were more abundant and two had a larger size and biomass in no-entry zones than no-take and fished zones, after 10 to >20 years of protection. Densities of apex predators and browser herbivores were higher in the no-take zone compared to both the no-take and fished zones but there were no differences between areas for targeted and non-targeted medium-sized predators and two other groups of herbivorous fish (data reported graphically and as statistical results). Fish size and biomass differed between areas only for the targeted and non-targeted predator groups and were higher in the no-entry zone than the other zones (data reported as statistical results). In addition, the differences in the predator groups due to protection level were not found to influence the density, size or biomass of the herbivorous fish groups. Reefs in three management zones within the Great Barrier Reef Marine Park were surveyed from October-April 2011–2013: no-entry (protection >20 years), no-take (protected 10–20 years where fishing is prohibited but non-extractive activities like diving are allowed), and fished areas. Fish were categorized into six groups according to food chain position and exploitation status (see original paper for details). At each reef (six per zone), apex predators were surveyed two to six times using 45-minute timed swims (20 m wide transect) and medium-sized predators and herbivores >10 cm total length using 10 to 16 transects (10 × 50 m).

A replicated study in 1993–2013 of 17 reef areas off Cocos Island, in the eastern Pacific Ocean, Costa Rica (64) found that over a period of 21 years, eight of twelve shark and ray species declined in abundance or presence inside a no-fishing marine protected area established for over 15 years, and poor enforcement may have contributed to the decline. Percentage declines in observed abundance in the period from 1993 to 2013 were recorded for six of twelve species (scalloped hammerhead *Sphyrna lewini*: 45%, whitetip reef shark *Triaenodon obesus*: 77%, marble ray *Taeniura meyeni*: 73%, eagle ray *Aetobatus narinari*: 34%, mobula ray *Mobula* spp.: 78%, manta ray *Manta birostris*: 89%) and declines in the likelihood of occurrence recorded for two (silky shark *Carcharhinus falciformis*: 91%, silvertip shark *Carcharhinus albimarginatus*: 87%). The likelihood of occurrence of four species increased between 1993 and 2013: tiger sharks *Galeocerdo* *cuvier* (79%/yr, Galapagos sharks *Carcharhinus galapagensis* (33%/yr), blacktip reef sharks *Carcharhinus limbatus* (9%/year) and whale sharks *Rhincodon typus* (5%/yr). In addition, the authors reported inadequate enforcement of fishing controls were likely to contribute to the declines. The Cocos Island National Park was designated in 1978, and extended in 1984 and 2001, covering 22.2 km around the island. Fishing is banned within the park but enforcement is poor and illegal shark fishing occurs. From 1993 to 2013 divers surveyed sharks and rays at 17 sites within the reserve by underwater visual census for one hour. Sites were between 10 and 40 m depth. Common species were recorded as count data and analysed as relative abundance while presence-absence data were recorded for rare species and analysed as odds of occurrence.

A site comparison study in 2009–2014 of a coral reef area off San Miguel Island in the Philippine Sea, Philippines (65) found more fish species and a higher overall fish abundance of commercially important fish in a no-entry/no-fishing zone of a marine protected area, compared to two partially fished zones and unprotected fished areas 10 to 15 years after implementation, and the effect of protection varied between individual species groups and sizes. Across all years, the average species richness and fish abundance of commercially important species was higher inside the no-entry zone (species: 11–12, abundance: 28–41 fish/transect) than elsewhere and was similar between partially fished protected zones (species: 3–8, abundance: 5–30 fish/transect) and non-protected fished areas (species: 4–7, abundance: 10–15 fish/transect). For the top six commercial fish family groups, the abundance of market-sized individuals of five groups differed between areas, whereas for non-target sizes only one differed (see paper for individual data). The San Miguel Island Marine Protected Area was designated in 1998 and has three zones with different levels of protection: a 1.0 km^2 sanctuary area (no fishing or recreational activity), a 1.25 km^2 partially protected area (traditional fishing types - gillnet, spear, trap, longline - permitted), and an outer 100 m buffer protected zone with less restriction (not specified). In May 2009 and 2010 and December 2014, fish were surveyed in each of the three zones and the adjacent unprotected area by underwater visual census along a total of 10 haphazardly placed transects (50 m^2) at least 10 m apart. Transects were located at reefs 1.3 km offshore and at depths of 9–21 m.

A site comparison study in 2013 of a rocky seabed area in the Atlantic Ocean, off southwest Portugal (66) found that a marine protected area where all fishing activity (except barnacle extraction) is prohibited, had a similar total fish species richness, a higher biomass and size, but not density, of seabream *Diplodus* spp. and a similar abundance, size and biomass of dreamfish *Sarpa salpa* and wrasses *Labrus* and *Coris* spp. compared to an adjacent fished area after two years. Average fish species richness was similar inside (7.8) and outside (4.5) the protected area. Biomass and size of *Diplodus* spp. was higher inside (biomass: 262 vs 105 g/100 m^2; size: 11.3 vs 5.1 cm), but density was similar (3.9 vs 5.4 fish/100 m^2). Similar density, size and biomass were recorded inside and outside the protected area for dreamfish (data not reported), and the wrasses *Labrus* spp. (density: 0.8 vs 0.3 fish/100 m^2; size: 18.4 vs 16.0 cm; biomass: 207 vs 21 g/100 m^2) and *Coris* sp. (density: 2.0 vs 4.5 fish/100 m^2; size: 6.4 vs 4.3 cm; biomass: 47 vs 107 g/100 m^2). In 2011, all fishing activity bar the extraction of barnacles was banned in the marine section of the Natural Park of the Southwest Alentejo and Vicente Coast (28,858 ha). In February and May 2013, fish were surveyed at two locations inside the protected area and two in an adjacent fished area (all fishing permitted, except bottom trawling and recreational fishing on Wednesdays). At each location two 40 m transects were swum by divers and the number and total length of all fish except small benthic species were recorded.

A site comparison study in 2012–2014 in shallow, sandy inshore areas in the western Atlantic Ocean off South Caicos in the Turks and Caicos Islands, UK (67) found that banning all fishing in a marine reserve resulted in a higher abundance of immature lemon sharks *Negaprion brevirostris*, particularly of smaller sizes, and similar shark growth rates but lower condition, compared to fished areas outside, after 20 years. Average abundance of immature lemon sharks was higher inside (0.56 sharks/h) than outside (0.36 sharks/h) the reserve and there were more smaller individuals (data presented graphically). Average condition factor was lower inside the reserve than outside, but growth rates were similar (data reported as statistical tests). The Bell Sound Nature Reserve was established in 1992 to protect bonefish *Albula Vulpes* and no fishing activity is permitted. Between February 2012 and August 2014, sharks were sampled year-round at 12 sites on a rotating basis (seven inside and five outside) using square-mesh gillnets (100 m long by 1.83 m deep, 6.35 cm mesh size). Nets were set perpendicular to shore for 1–6 h. Sharks (new and recaptured tagged individuals) were removed from nets immediately after capture, weighed and the total length measured. New individuals were marked with both a plastic tag and a data recording tag.

A site comparison study in 2013–2014 of two coral reef sites in the Indian Ocean off southwest Madagascar (68) found that overall species richness and abundance of post-larval fish was similar at reefs where all fishing was prohibited for 15 years compared to fished reefs, and individual fish species or family groups differed with changes in water temperature, salinity and/or transparency. Overall, the non-fished reef had a similar average number of fish species/families (non-fished: 3–6, fished: 1–9) and post-larval abundance as the fished reef (non-fished: 5–24; fished: 2–26). In addition, the most dominant and frequent species/families differed between reefs (see paper for individual data) but this was influenced by sea surface temperature, salinity and water transparency. Two differing reef sites 50 km apart were surveyed monthly (except November) in August 2013–February 2014; a protected reef off Anakao (10 km^2, protected from fishing since 1999) and a fished site in the Great Reef of Toliara, with reduced coral diversity. Fish post-larvae were sampled at three locations per site using light-traps and transferred live to a laboratory for identification to the lowest taxonomic level possible.

A replicated, site comparison study in 2002–2012 of sixteen rocky coral reef sites in a marine park in the Tasman Sea, New South Wales, Australia (69) found that banning all fishing in areas of the park resulted in increased fish abundances of six of 12 fishery targeted and non-targeted species or groups compared to areas where some fishing types are allowed, and the effect varied with size and age (small, 10–20 years and large, 0–10 years) of the area protected. Across all years, average abundances of five of ten targeted and one of two non-targeted fish species/groups (see paper for details) were higher at a non-fished area than at fished areas, and no effect of management type was found for the other six (data reported as statistical results and presented graphically for some species only). In addition, the effect of management type was generally higher for large no-fishing areas, and four of the six fish groups that differed with management type were more abundant in larger no-fishing areas within a few years of establishment compared with small no-fishing and fished areas (data reported as statistical results). Fish assemblages were surveyed annually in 2002–2007, 2009 and 2012 at 16 sites, 9–16 m depth, in the Solitary Islands Marine Park. Four sampling sites were in each of four management areas (two no-take and two fished): small, no-fishing (<15 ha, established 1991), large, no fishing (>100 ha, established 2002), recreational fishing but no commercial fish trapping (>200 ha), and recreational fishing and commercial fish trapping (>200 ha per site). At each site, fish were recorded along six underwater visual transects (125 m^2) and during three replicate five-minute timed-swim counts (250 m^2).

A study in 2008–2010 of an area of reef in a coastal marine park in the Indian Ocean, off western Australia (70) found that the time sharks spent inside a small protected area of the park where all fishing was prohibited for 20 years varied between three species and that immature sharks were more likely to remain in the protected area than adults, and thus receive more protection from fishing. Sicklefin lemon sharks *Negaprion acutidens* spent 98–99% of time in the no-fishing protected areas, blacktip reef sharks *Carcharhinus melanopterus* 0–99% and grey reef sharks *Carcharhinus amblyrhynchos* less than 1% of time. Immature sharks were located inside the no-fishing areas for 84–99% of time and adults 0–99%. In addition, immature sharks moved within smaller areas (0.6–8.5 km^2) than adults (3.6–21.8 km^2). Ningaloo Reef is the largest fringing reef in Australia (260 km long) and is protected by the multiple-use Ningaloo Marine Park established in 1987. Commercial fishing is prohibited and there are 18 no-fishing marine protected areas (884 km^2). Sharks were caught and tagged in the marine park at beaches inside (by handlines) and outside (by longlines) a no-fishing area (11.35 km^2) in February 2008 and November 2009. A total of 56 acoustic receivers deployed inside and outside the no-fishing area recorded tagged shark location every 30 minutes for up to two years. The movement data for 12 sharks consistently detected for six months or more were analysed.

A site comparison study in 2008 of two submerged rocky cliff areas in the Tyrrhenian Sea, Italy (71) found higher overall fish species richness, higher fish abundance and biomass overall and for fisheries target species, and similar abundance and biomass of non-target fish inside a no-take zone of a marine protected area where all fishing was banned, compared to fished areas, although the effect varied with depth. Overall fish species richness, total abundance and total biomass were higher inside the no-take zone than fished areas at all depths (species richness: 14–18 vs 9–9, abundance: 235–357 fish vs 125–141 fish, biomass data reported as log-transformed). The abundance of targeted fish species was higher inside the no-take zone than fished areas at shallower depths (5 m: 136 vs 30, 10 m: 194 vs 25) but not at the deepest (20 m: 41 vs 23), and biomass was higher inside at all depths (data log-transformed). Abundance and biomass of non-target fish species were similar between areas (data reported as statistical results). The marine protected area at Punta Campanella (1,300 ha, year of designation not reported) extends from the coastline to 60 m depth and has two no-take areas. Underwater visual censuses were undertaken in June and October 2008 at one of the no-take zones where all fishing is banned (21 ha), and six partially protected sites where only some fishing (local fishers only and small vessels <10 gross tonnage) and other activities like diving are allowed. Fish were recorded along transects (25 m × 5 m × 5 m) at three depths (5 m, 10 m, 20 m). Three replicate transects were surveyed at each depth.

A site comparison study in 2010–2011 at 12 coral reef sites in the Sulu Sea, Malaysia (72) found that prohibiting all fishing in a marine reserve resulted in a greater total fish density and biomass, and a higher biomass but similar density of coral trout *Plectropomus* spp., compared to fished areas outside, 11 years after implementation. Overall, areas closed to fishing had a higher reef fish density (closed: 624 fish/250 m^2, fished: 373 fish/250 m^2) and biomass (closed: 40 kg/250 m^2, fished: 12 kg/250 m^2) than fished areas. Average coral trout biomass was greater in closed (1.3 kg/250 m^2) compared to fished areas (0.1 kg/250 m^2), but density was similar (closed: 1.5 fish/250 m^2; fished: 0.4 fish/250 m^2). Sugud Islands Marine Conservation Area (467 km^2) was established in December 2001 and prohibits fishing. Between April 2010 and November 2011, twelve patch reefs around Lankayan Island were surveyed: eight reefs in the reserve area closed to fishing and four open to fishing outside (0–3 km from the reserve border). Fish >3 cm length were recorded (count and species) by diver visual census along four randomly placed belt transects, 5 m wide by 50 m length, at each reef site (minimum 50–100 m apart). Fish biomass was estimated using length–weight relationships.

A site comparison study in 2015 of 22 estuaries in the Tasman Sea, Australia (73) found that prohibiting all fishing in estuarine reserves for between seven-12 years resulted in greater abundance of two of two non-harvested fish species, but lower abundance of four of four commercially harvested fish, compared to fished areas. Average abundance of species not harvested in the region (estuary perchlet *Ambassis marianus* and blue catfish *Neoarius graeffei*) was higher in unfished estuarine reserves than fished estuaries (unfished: 0.48–9.57 ind, fished: 0.12–6.33 ind), whereas average abundance of four fisheries-targeted species (yellowfin bream *Acanthopagrus australis*, grey mullet *Mugil cephalus*, common toadfish *Marilyna pleurosticta*, weeping toadfish *Torquigener pleurogramma*) was lower in the unfished reserves (unfished: 0.06–3.16 ind, fished: 0.39–8.99 ind). In addition, fish communities were different between unfished reserve and fished estuaries (data reported as a graphical analysis). The authors noted that differences in the environmental attributes between the unfished and fished estuaries contributed to the lower abundance in unfished estuaries for harvested fish. Data were collected between June and August 2015 in six no-take (no extractive activities, including fishing; one established 1993, the rest 2008) and 16 fished estuaries in the Moreton Bay Marine Park (created 1993). Fish were surveyed twice (for 1 h) over two days at ten sites (>250 m apart) in each estuary by baited remote underwater video. Counts were made of the maximum numbers of individual fish visible by species.

A site comparison study in 2014 at two rocky sites in a bay in the North Sea off western Norway (74) found that the commercial fishing mortality of corkwing wrasse *Symphodus melops* originally tagged at a small temporary marine protected area where fishing is prohibited was reduced compared to wrasse tagged at a fished site, but there was a similar selective removal of fish by size and sex regardless of site of origin. Overall fishing mortality of wrasse tagged inside the no-fishing site was lower than wrasse tagged in a fished site (not fished: 6–9%, fished: 31–41%). However, fishing mortality of nesting male wrasse (not fished: 12–15%, fished: 36–49%) was higher than for females (not fished: 3–5%, fished: 29–36%) at both sites. Average total length of nesting males was 119–141 mm and females 131–136 mm. In 2014, a total of 1,057 corkwing wrasses were tagged during (May–June) and after (July) the spawning period: 492 within a temporary no-fishing site (600 m of coastline, duration of protection was not reported) and 565 in a nearby site with no fishing restrictions. Fishing mortality of tagged wrasse was determined by recording the numbers captured and retained on all commercial potting fishing trips occurring within the bay over a three-month period.

A site comparison study in 2007–2013 of 23 coral reef sites inside a marine reserve in the Caribbean Sea off Belize (75) found that the effects of prohibiting all fishing for 14–20 years on fish density, biomass and size varied with level in the food chain of five representative fish species/groups, compared to fished reserve zones. Data were presented graphically and as statistical results. Trends over time showed increases in average fish densities (fish/ha), biomasses (g/ha) or sizes (length to tail fork, mm) in the unfished zone compared to the fished zone: for large, and small, plant/algae-eating fish (*Scaridae* spp.), one invertebrate-eating fish (hogfish *Lachnolaimus maximus*) and two of three predatory (fish and/or invertebrates) fish (Nassau grouper *Epinephelus striatus* and black grouper *Mycteroperca bonaci*). Average density and biomass of the other predatory species (mutton snapper *Lutjanus analis*) showed no clear trends over time in the unfished zone, but size decreased. Black grouper density decreased, and biomass remained steady in both the unfished and fished zones, and small herbivores decreased in both unfished and fished areas over time. Diffferences between the unfished and fished zones were generally greater for the species at lower levels of the food chain (e.g. plant/algae eaters). Glover's Reef Atoll was established as a Marine Reserve in 1993 and has several management zones including no-take (80 km^2, all fishing banned), and general use (270 km^2, fishing permitted, with regulations – see original paper for details). Fish in five no-take patch reefs and six fished reefs were monitored between 2007–2009, increased in 2010–2013 to include 12 additional fished reefs. Each reef was sampled once a year during April, May, or June. Fish number and estimated size over the entire area of each reef down to 3 m was recorded by snorkellers.

A before-and-after study in 2007–2011 of reef and lagoon areas of an inhabited coral reef island in the Pacific Ocean, Tonga (76) found that in the five years following the creation of a no-take fishing zone in a newly co-managed area that also excluded fishers from outside areas, the total fish catch rates in landed catches from the co-managed area did not increase, catch rates of half of the six individual species groups decreased and there was no decrease in overall fishing effort. No differences in total fish catch rates and catch rates of three of six fish groups (*Acanthuridae - Naso spp., Holocentridae, Lethrinidae*) were found since implementation, but catch rates of the remaining three (*Acanthuridae - Acanthurus spp., Scaridae, Serranidae*) decreased (data reported as statistical results). In addition, no difference in overall fishing effort was found (data reported as statistical results), but the authors reported that this was likely to be due to reduced travel to fishing grounds further away by resident fishers with the new exclusive rights. Co-management formally commenced on the island of 'O'ua (one of 170 Tongan Islands) in 2007, covering a marine area of 4,606 ha, of which 203 ha is a no-take zone. Only residents on 'Ou'a can fish the co-managed area. Fish catches were sampled (species and weight per trip) each year between 2007–2011 (total 184 records), collected opportunistically from landings by individual fishers (see original paper for fishing types). Catch data from spearfishing only was used for statistical analysis.

A site comparison study in 2006–2013 of a large area of coral reef atolls in an island chain in the Pacific Ocean, USA (77) found that commercial fishing mortality of grey reef sharks *Charcharhinus amblyrhnychos* tagged at a large marine reserve where all fishing was banned for at least five years appeared to be low, and most of the sharks tracked by satellite remained inside the reserve, while some moved over large distances outside. The data were not statistically tested. Only 2% (five) of the 262 conventional tags deployed on sharks were recovered (the rest were either not caught or not reported), captured by small-scale fisheries at locations outside the reserve between 223–366 km away on average 587 days after tagging. Four of six sharks tracked by satellite remained inside the reserve boundaries for the entire monitoring period (1.3 years), and two were detected outside the reserve for 9% and 57% of time, travelling distances of up to 88 and 810 km respectively. Recovery of satellite-tagged sharks was not reported. Palmyra Atoll National Wildlife Refuge (54,126 km^2) was established in 2001 (boundaries extended in 2009 and 2014) and prohibits all fishing and other extractive activities. From October 2006 to July

2009, a total of 262 grey reef sharks were caught in the reserve and marked with conventional tags on the dorsal fin. Recovered tags were actively sought (in 2007, 2009 and 2013) and encouraged from fishers at the three nearest inhabited and fished atolls several hundred kilometres away. During the same period, 11 fin-mounted satellite tags were deployed on adult sharks at the reserve, providing adequate data on the movements of six.

A site comparison study in 2015–2016 of five areas of mixed seabed type (sand/seagrass/mangrove) in the Tasman Sea, eastern Australia (78) found that over 15 months, giant shovelnose rays *Glaucostegus typus* spent more than half of the time inside marine reserves where all fishing was prohibited compared to fished areas outside, and it varied seasonally. Data were not statistically tested. Overall, rays were detected inside no-fishing areas compared to fished areas 58% of the days. In addition, ray detections inside the no-fishing reserves varied with season (winter: 53%, rest of year: 23%). Shovelnose rays were tracked from January 2015 to March 2016 in and around five marine reserves (fishing and extractive activities prohibited; the year established was not reported) located in Moreton Bay Marine Park. A total of 20 rays were surgically fitted with acoustic transmitters and released at two seagrass sites adjacent to reserves. The rays were tracked by 28 receivers (covering 180 km^2) located in no-fishing and fished areas. Tracking data were analysed for 16 rays detected by receivers for longer than seven days, up to the removal of the receivers fifteen months later.

A review of ten studies of the effectiveness of different types of marine protected areas (study areas were not reported) (79) found that the total biomass of fish populations was highest in no-take marine protected areas relative to adjacent partially protected (some fishing permitted) marine protected areas and openly fished unprotected areas. The biomass of the whole fish assemblage was on average 670% greater within no-take protected areas than unprotected areas, and 343% greater than in partially protected areas. Fish biomass in partially protected areas was 183% greater than unprotected areas and was often similar. In addition, recovery of fish biomass over time was found in no-take areas after protection (nine–19 years), but not in partially protected or unprotected areas (data presented as log-ratios). The review surveyed peer-reviewed studies (total number not reported) documenting the biomass of whole fish assemblages of no-take marine reserves, partially protected marine protected areas, and open access areas all within the same vicinity. A meta-analysis of seven published and three unpublished studies (author and year reported only) comparing biomass data between all three areas was done.

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2.16 Cease or prohibit all fishing activity in a marine protected area with limited exceptions

- **Four studies** examined the effects of ceasing or prohibiting all fishing activity in a marine protected area with limited exceptions on marine fish populations. One study was in each of the Pacific Ocean[1] (USA), the Caribbean Sea[2] (US Virgin Islands), the Great Barrier Reef[3] (Australia) and the Skagerrak[4] (Norway).

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study)**: One site comparison study in the Caribbean Sea[2] found that in marine protected areas closed to all fishing with limited exceptions for up to seven years, there was lower total fish species richness compared to unprotected areas.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (2 studies)**: One replicated, site comparison study in the Pacific Ocean[1] found that abundance of copper rockfish, quillback rockfish, china rockfish and lingcod was similar between non-voluntary and voluntary 'no-take' reserve sites where all fishing with limited exceptions had been prohibited for one to eight years, and sites open to fishing. One site comparison study in the Caribbean Sea[2] found that restricting all fishing activity except for bait fishing in marine protected areas for seven years resulted in similar total fish biomass and lower total fish density, compared to unprotected areas.
- **Survival (1 study)**: One replicated, controlled, before-and-after study in the Skagerrak[4] found that cod survival increased inside a marine protected area in the eight years after almost all fishing was prohibited, compared to outside areas fished with a wider range of gear types.

BEHAVIOUR (1 STUDY)

- **Use (1 study)**: One replicated study in the Great Barrier Reef[3] found that immature pigeye sharks and adult spottail sharks were detected frequently and over long time periods inside marine protected areas five years after prohibiting almost all fishing except restricted line fishing and bait netting, thus reducing the overall likelihood of fishing mortality.

Background

Marine Protected Areas are designations for marine sites in which fish (and other marine animals and habitats) conservation can be promoted through management of the fishing activity and other human activities. Many protected areas are 'no-take' areas in which no harvesting or collection of marine organisms is permitted by any method. However, some may prohibit almost all harvesting but permit very limited fishing activity (i.e. only one type of harvest activity and/or target species), typically those that are considered to be more selective and have no impact on the bottom habitat. depending on the purpose and the characteristics of the species or habitats intended to be conserved. Ceasing or prohibiting almost all fishing activity may benefit previously impacted populations by allowing them to recover from the effects of fishing over time, whilst allowing the limited use of other resources in the protected area or for it to be used for a specific purpose with potentially little or no impact.

Evidence for similar interventions relating to prohibiting human activity, including fishing, in marine protected areas is summarized under *'Cease or prohibit all types of fishing in a marine protected area'*, *'Control human activity in a marine protected with a zonation system of restrictions*' and '*Restrict fishing activity (types unspecified) in a marine protected area*'.

A replicated, site comparison study in 1998 of eight rocky and sandy sites in the San Juan Archipelago, northwest Pacific Ocean, USA (1) found no differences in the abundances of copper rockfish *Sebastes caurinus,* quillback rockfish *Sebastes maliger,* China rockfish *Sebastes nebulosus* and lingcod *Ophiodon elongatus* between voluntary no-take sites (no collection of finfish except for salmon) protected for one year, no-take sites (all collection of marine organisms prohibited except for approved scientific research) protected for eight years, and nearby sites open to fishing. Results were reported only as statistical results (ordination analyses). The authors suggested the lack of increase in fish abundance inside protected compared to non-protected areas was likely due to a lack of compliance and enforcement of the restrictions. In July 1998, two marine protected areas (designated 1997 as voluntary no-take zones where no finfish except salmon could be collected – no gears specified), three research marine reserves (established 1990, extractive activities prohibited except for research, sea urchin fishery closed since late 1970s), and three unprotected openly fished areas were surveyed. Two divers identified and counted fish along 300 m^2 transects on reef slopes up to 20 m deep (4 transects/site).

A site comparison study in 2003–2008 of two reef areas in the Caribbean Sea, US Virgin Islands (2) found that prohibiting almost all fishing except for bait within a marine protected area resulted in lower fish species richness and density and similar fish biomass compared to adjacent unprotected areas in the seven years after protection. Species richness and fish density was lower inside the protected area than outside (species richness: 24 vs 27 species/100 m^2; density 229 vs 294 fish/100 m^2) and biomass was similar (inside: 7,900, outside: 8,800 g/100 m^2). The Virgin Islands Coral Reef National Monument was established in 2001 to extend the existing Virgin Islands National Park. In the study area, all extractive uses and boat anchoring were prohibited, except for a small area where bait fishing was permitted (no species or gears specified). Annually, in July 2003–2008, protected areas (18–20 sites/year) and fished areas (15–18 sites/year) were surveyed. Divers recorded fish number, length and species along 25 × 4 m belt transects. Biomass was estimated using average length for each size class.

A replicated study in 2009–2010 of two shallow coastal areas in the Great Barrier Reef, Coral Sea, Australia (3) found that individuals of two shark species displayed frequent and long-term use of marine protected areas prohibiting all fishing (except restricted line fishing and bait netting) for five years, and thus were protected from fishing for a proportion of time. Immature pigeye *Carcharhinus amboinensis* and adult spottail *Carcharhinus sorrah* were detected inside protected areas an average of 23% (range 2–67%) and 32% (range 0–67%) of time respectively, and for 4–676 days (average 190 days) and 28–566 days (average 281 days). In addition, the amount of time spent inside protected areas was significantly different between sexes for spottail, but not pigeye, with female spottail spending more time (38%) than males (21%). All the tracked sharks left the protected areas during monitoring, on average 0.9 times/day for pigeye and 1.7 times/day for spottail. Sharks were monitored in two marine protected areas in Cleveland Bay (140 km^2) off the wider Great Barrier Reef Marine Park (rezoned in 2003) in which trawling and netting (bait netting excluded) are prohibited and line fishing is limited to one line per person and one hook per line. Sharks are not targeted by the permitted fisheries and 95% are released alive if captured. From 2009 to 2010, tracking data was collected from 37 sub-adult pigeye and 20 adult spottail fitted with acoustic transmitters by 55 underwater receivers deployed inside the two protected areas.

A replicated, controlled, before-and-after study in 2005–2013 of three seabed areas in the Skagerrak, Norway (4) found that in a marine protected area prohibiting almost all fishing, except for commercial hook and line fishing of cod *Gadus morhua* and research sampling, cod survival increased over eight years, compared to outside areas where a wider range of fishing gear types were allowed. Overall average survival probability of cod inside the protected area increased after implementation (after: 0.2–0.4, before: 0.1–0.2) and in comparison with areas outside the protected area (after: 0.2, before: 0.2). Sampling was done in April–July 2005–2013. Cod were captured inside the protected area and at two unprotected sites with fyke nets and tagged and released at the capture location. Data on 10,764 recaptures of tagged fish were used: 1,454 tagged within the protected area and 9,310 tagged in other areas along the Skagerrak coast. Survival was estimated using a model, described in the original paper. The protected area (Flødevigen, 1 km^2) was implemented in September 2006 and allowed a hook and line fishery and research sampling. At unprotected areas, hook and line, gillnets, fyke nets and other fishing gear types were allowed, but not bottom trawling within 12 nautical miles from the coast, with an exception for small scale coastal trawling for shrimp *Pandalus borealis*.

(1) Tuya F.C., Soboil M.L. & Kido J. (2000) An assessment of the effectiveness of Marine Protected Areas in the San Juan Islands, Washington, USA. *ICES Journal of Marine Science*, 57, 1218–1226.

(2) Monaco M.E., Friedlander A.M., Caldow C., Hile S.D., Menza C. & Boulon R.H. (2009) Long–term monitoring of habitats and reef fish found inside and outside the U.S. Virgin Islands Coral Reef National Monument: A comparative assessment**.** *Caribbean Journal of Science***,** 45, 338–347.

(3) Knip D.M., Heupel M.R. & Simpfendorfer C.A. (2012) Evaluating marine protected areas for the conservation of tropical coastal sharks. *Biological Conservation*, 148, 200–209.

(4) Fernández-Chacón A., Moland E., Espeland S.H. & Olsen E.M. (2015) Demographic effects of full vs. partial protection from harvesting: inference from an empirical before-after control-impact study on Atlantic cod. *Journal of Applied Ecology*, 52, 1206–1215.

2.17 Control human activity in a marine protected area with a zonation system of restrictions

- **Eight studies** examined the effects of controlling human activity in a marine protected area with a zonation system of restrictions on marine fish populations. Three studies were in the Indian Ocean[1,4,5] (South Africa), two were in the Coral Sea[6,8] (Australia), and one was in each of the Southern Atlantic Ocean[2] (South Africa), the Ligurian Sea[3] (Italy) and the Philippine Sea[7] (Philippines).

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One site comparison study in the Philippine Sea[7] found a higher number of fish species in the no-fishing/no access zone of a multi-zoned marine protected area compared to two partially fished zones and unprotected fished areas 10 to 15 years after implementation.

POPULATION RESPONSE (4 STUDIES)

- **Condition (4 studies)**: Two of four site comparison studies in the southern Atlantic Ocean[2], Ligurian Sea[3], Indian Ocean[4] and the Coral Sea[6] found that controlling human activity in marine protected areas with a zonation system of restrictions resulted in larger average lengths of steentjies[2] and three seabream species three years after implementation[3] compared to unprotected fished areas, and lengths were largest within a no-take zone than a partially fished zone[2]. Two other studies[4,6] found larger sizes of four of four coral reef fish in a zone where nearly all fishing is prohibited compared to an adjacent zone with fewer fishing restrictions two to seven years after protection[4], and of two of six fish feeding groups in no-entry zones compared to both no-take and fished zones protected between 10 and 20 years[6].
- **Abundance (6 studies)**: Two of four site comparison studies (one replicated) in the Ligurian Sea[3], Philippine Sea[7] and the Coral Sea[6,8] found that controlling human activity in protected areas with a zonation system of restrictions resulted in a greater biomass and/or abundance of fish species after 3–15 years compared to unprotected areas outside[3,7], and between the zones fish abundance varied with the level of restriction[3,7] and between individual fish groups and sizes[7]. The other two studies[6,8] found higher density, biomass[6,8], and abundance[6] of fish in non-fished zones (no-entry and no-take) compared to fished zones inside areas protected for 10 to 27 years depending on region, but the effect varied between fish feeding groups[6,8], zone protection level[6,8] and reef region[8]. One site comparison study in the Indian Ocean[4] found higher abundances of four of four reef fish species in a zone where nearly all fishing is prohibited, compared to an adjacent zone with fewer fishing restrictions. One site comparison study in the Southern Atlantic Ocean[2] found that steentjies in a protected zone closed to fishing but open to other recreational activities had a different age and sex structure to a fished multipurpose zone, and both were different to a distant unprotected fished site with low steentjie exploitation.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** Two site comparison studies in the Indian Ocean[1,5] found that in marine protected areas with zonation systems of activity controls, most of the individuals of the reef fish species tagged and released inside the protected areas were recaptured again at almost the same locations over the following nine[1] or four years[5], and mainly in the zones where all[1] or nearly all[5] fishing was prohibited for up to 20 years, indicating increased protection from fishing.

Background

Marine Protected Areas are legally protected marine sites in which fish (among other marine animals and habitats) conservation can be promoted through controls on the fishing and other human activities that take place within its boundaries. The level of protection varies widely in protected areas, from the banning of all human access to permitting selected activities including some fishing types. Marine protected areas that want to allow a wide range of human activities are generally divided into zones with different rules on access and use in each. They may typically have reserve zones where all fishing is prohibited and 'partially-protected zones' that allow fishing with specified gears or for certain species only. Zoning of marine protected areas is considered an easy management measure to implement (Sale 2002) and is a way of providing or maintaining socio- and economic benefits to local regions and communities.

Evidence for similar interventions relating to prohibiting human activity, including fishing, in marine protected areas is summarized under *'Cease or prohibit all types of fishing in a marine protected area'*, *'Cease or prohibit all fishing activity in a marine protected area with limited exceptions*' and '*Restrict fishing activity (types unspecified) in a marine protected area*'.

Sale P.F. (2002) Coral reef fishes: Dynamics and Diversity in a Complex Ecosystem. Elsevier Science, USA.

A site comparison study in 2001–2013 of four surf-zone sites in the Indian Ocean, off South Africa (1) found that the majority of recaptures of tagged fish from five species made over a nine-year period, occurred inside a marine reserve where fishing activity was controlled by zones, mainly in the no-take zone where all fishing has been banned for over 20 years. Most individuals of the five main study species were recaptured within 200 m of their original release site: grey grunter *Pomadasys furcatus*: 88%, catface rockcod *Epinephelus andersoni*: 84%, yellowbelly rockcod *Epinephelus marginatus*: 92%, cavebass *Dinoperca petersi*: 88% and speckled snapper *Lutjanus rivulatus*: 79%. Overall, 61% of fish were originally tagged at sites in the no-take zone and the rest in the zone that allows shore angling, recreational boat angling and spearfishing for pelagic gamefish only. In addition, the maximum times between release and capture ranged from 287–3,163 days; average recapture rate was 29%, and 632 of the 3,224 fish tagged were recaptured at least once. The St Lucia Marine Reserve in South Africa was established in 1979. From November 2001– 2013, a total of 6,613 fish from 71 species were tagged and released at four sites in the reserve: two in a no-take zone and two in a restricted fishing zone. Over the same sampling period, details of fish recaptured in the reserve by the research team and angling public, and other reported recaptures in fished areas outside the reserve were recorded.

A site comparison study in 2006–2007 of three seabed sites in the Southern Atlantic Ocean, off South Africa (2) found that in a multi-zoned protected area steentjies *Spondyliosoma emarginatum* in a zone closed to all fishing were larger, and had a different age and sex structure, than a fished multipurpose zone and both showed differences to a distant unprotected fished site with low steentjie exploitation. Overall, average size of steentjies was larger in the no-fishing protected zone than the fished zone (non-fished: 238–271 mm, fished: 210–262 mm) and both were larger compared to a distant unprotected fished site (187–218 mm). The frequency of females was highest in the fished protected zone (reserve non-fished: 53%, reserve fished: 83%, distant non-targeted: 39%) and the frequency of males was highest at the distant site (reserve non-fished: 17%, reserve fished: 5%, distant non-targeted: 57%) (transitional males make up the difference). In addition, larger and older females and larger male steentjies were fewer in the fished protected zone compared to the no-fishing zone (data presented graphically). Steentjies were captured by line fishing at two sites inside Langebaan Lagoon reserve in April-September 2007. One site was a no-fishing zone permitting sailing and canoeing only and one was a multi-purpose recreational zone permitting fishing and other activities (year of implementation not reported). Steentjies were also caught at a third site off Struisbaai by research vessel from November 2006 to April 2007. Commercial and recreational fishing is permitted but steentjies are not generally targeted. A total of 319 steentjies were sampled for length, sex and age.

A site comparison study in 2004–2005 of four rocky reef areas in the Ligurian Sea, Italy (3) found that length, biomass and density of three seabream *Diplodus* species was greater in a three year old marine protected area split into three fishing management zones, compared to adjacent unprotected fished areas, and differences between zones varied with sampling season (length) and level of restrictions (biomass and density). The average seabream length was greater in all three zones of the protected area than outside (inside: 12–24 cm, outside: 8–13 cm), however differences between the protected zones varied with sampling season. The density and biomass of sharpsnout seabream *Diplodus puntazzo* varied between protected zones and was higher overall than outside the protected area (results reported as statistical analysis). White seabream *Diplodus sargus* density and biomass was higher inside compared to outside, except in the management zone with intermediate protection where only biomass was higher and was affected by zone and sampling time. The biomass, but not density, of common two-banded seabream *Diplodus vulgaris* differed between protected zones and was higher in the two management zones with a greater level of protection compared to outside. The Portofino marine protected area (346 ha) was established in 1999, with protection enforced in 2001. Three levels of management protection were in place: a no-entry, no-take zone, a zone permitted only for local traditional commercial and recreational fishers (see paper for specified gears), and a zone where, in addition, non-resident shore fishing with hook and line is permitted. Fish were sampled by underwater visual census (25 × 5 m transects) in November 2004 and 2005 at two sites in each management zone of the protected area and at six sites in unprotected areas.

A site comparison study in 2006–2011 of two coral reef areas in a zoned marine protected area in the Indian Ocean, South Africa (4, same experimental set-up as 5) found higher abundance and larger size of four of four coral reef fish species in a 'no-take' zone where almost all fishing is prohibited, compared to an adjacent zone with fewer fishing restrictions, two to seven years after protection. In each year, individual catch rates were higher inside the no-take zone than the fished zone for all four species: slinger *Chrysoblephus puniceus* (3.1 vs 0.8 fish/angler/h), Scotsman *Polysteganus praeorbitalis* (1.2 vs 0.3 fish/angler/h), poenskop *Cymatoceps nasutus* (0.4 vs 0.2 fish/angler/h) and yellowbelly rockcod *Epinephelus marginatus* (0.6 vs 0.1 fish/angler/h). Average lengths were also higher (slinger: 293 vs 240, Scotsman: 415 vs 359, poenskop: 417 vs 380, rockcod: 495 vs 435 mm). In addition, three of the four species (slinger, Scotsman, rockcod) showed increases in size over time (data not tested statistically). The Pondoland Marine Protected Area (800 km^2) was designated in 2004 and comprises a central 'no-take area' (400 km^2) closed to all offshore (vessel based) exploitation. On either side of the no-take zone are two controlled fishing areas where offshore line fishing and spearfishing are permitted. No commercial fishing, such as trawling or long-lining, is permitted anywhere in the protected area. From April 2006 to June 2011 quarterly research angling was conducted at two sites in the no-take zone and two in the nearby exploited zone (6 h angling in each zone) at 10–30 m depth. Data were analysed for four species that had been depleted by line fishing.

A site comparison study in 2006–2010 of four coral reef sites in the Indian Ocean, off South Africa (5, same experimental set-up as 4) found that the majority of recaptures of four of four fish species that were tagged inside a marine protected area where fishing activity is controlled by zones, occurred close to the original release site, mainly in the zone where nearly all fishing is prohibited, thus were protected from most fishing activity. Overall, 94% of recaptured individuals of four of four species were recorded within the same zone where they were originally tagged (mainly in the no-take zone), and most within 250 m of release site (Scotsman *Polysteganus praeorbitalis*: 72%, slinger *Chrysoblephus puniceus*: 76%, yellowbelly rockcod *Epinephelus andersoni*: 90%, catface rockcod *Epinephelus marginatus* 97%). In addition, recaptures for only 19 fish were recorded outside the protected area (3–1,059 km away). Recapture rates ranged from 8-60% and time between release and capture from 0 to 1,390 days. A total of 1,022 fish (780 in the no-fishing zone) of the four study species were tagged inside the two-zoned Pondoland Marine Protected Area (800 km^2, of which half is restricted no-take, year implemented was not reported) from April 2006 to July 2010. Fish data (tag recaptures) were collected quarterly in the protected area by line fishing at two sites in the 'no-fishing' zone (no offshore vessel based fishing) and two sites in a controlled fishing zone (permits offshore line fishing and spearfishing). No commercial fishing such as trawling or longlining is permitted anywhere in the protected area. Recapture data from areas outside the protected area were reported by the angling public.

A site comparison study in 2011–2013 of 18 coral reef sites in the Great Barrier Reef, Coral Sea, Australia (6) found that in a marine protected area where human activity has been controlled by zones for 10-20 years, two of six different groups of fish were more abundant and two had a larger size and biomass in no-entry zones than no-take and fished zones. Densities of apex predators and browser herbivores were higher in the no-take zone compared to both the no-take and fished zones but there were no differences between areas for targeted and non-targeted medium-sized predators and two other groups of herbivorous fish (data reported graphically and as statistical results). Fish size and biomass differed between areas only for the targeted and non-targeted predator groups and were higher in the no-entry zone than the other zones (data reported as statistical results). In addition, the differences in the predator groups due to protection level were not found to influence the density, size or biomass of the herbivorous fish groups. Reefs in three management zones within the Great Barrier Reef Marine Park were surveyed from October-April 2011–2013: no-entry (protection >20 years), no-take (protected 10–20 years where fishing is prohibited but non-extractive activities like diving are allowed), and fished areas. Fish were categorized into six groups according to food chain position and exploitation status (see original paper for details). At each reef (six/zone), apex predators were surveyed 2-6 times using 45-minute timed swims (20 m wide transect) and medium-sized predators and herbivores >10 cm total length using 10-16 transects (10 × 50 m).

A site comparison study in 2009–2014 of a coral reef area off San Miguel Island in the Philippine Sea, Philippines (7) found more fish species and a higher overall fish abundance of commercially important fish in a no-entry zone of a marine protected area, compared to two partially fished zones and unprotected fished areas 10-15 years after implementation, and the effect of protection varied between individual species groups and sizes. Across all years, the average species richness and fish abundance of commercially important species was highest inside the no-entry zone (species: 11–12, abundance: 28–41 fish/transect) and was similar between partially fished protected zones (species: 3–8, abundance: 5–30 fish/transect) and non-protected fished areas (species: 4–7, abundance: 10–15 fish/transect). For the top six commercial fish family groups, the abundance of market-sized individuals of five groups differed between all three levels of protection, whereas for non-target sizes only one differed (see paper for individual data). The San Miguel Island Marine Protected Area was designated in 1998 and had two zones with different levels of protection: a 1.0 km^2 sanctuary area (no fishing or recreational activity) and a 1.25 km^2 partially protected area (traditional fishing - gill net, spear, traps and line - permitted), with an outer 100 m buffer protected zone. The unprotected area was fished with active (e.g. seines) and passive gears. In May 2009 and 2010 and December 2014, fish were surveyed in each of the three zones and the adjacent unprotected open area by underwater visual census along a total of 10 haphazardly placed transects (50 m^2) at least 10 m apart. Transects were located at reefs 1.3 km offshore and at depths of 9–21 m.

A replicated, site comparison study in 2013–2014 of two coral reef regions of the Great Barrier Reef, Coral Sea, Australia (8) found that although density and biomass of fish from all feeding groups was higher at reefs in at least one of two non-fished zones (no-entry and no-take) in a marine park compared to fished zones, it varied with zone protection level and reef region. The density of only one of five fish groups (predators) was higher in non-fished zones at both of the reef regions; in two of two no-entry zones (5–6 fish/ha) and one of two no-take zones (5 fish/ha) compared to fished zones (1–3 fish/ha). For the remaining four groups in the food chain (commercially targeted and non-targeted mid-ranking predators, mobile herbivores and territorial grazers) fish density was higher in non-fished zones at one reef region only, and only at one of either the no-entry or no-take zones. Higher fish biomasses for all groups were similarly recorded in at least one no-entry or no-take zone across both regions, but the reef region it was reported in varied (see original paper for individual data). Between February–April in 2013 and 2014, two different regions of the Great Barrier Reef were surveyed by underwater visual census, six reefs (two/management zone) in the Ribbon Reef region (~50 km^2) and nine reefs (three/management zone) in the Swains Reef region (~100 km^2). Management zones allowed different activities: no-entry zones closed to all human activities, no-take zones that prohibited extractive activities (fishing) but permitted diving and boating, and fished zones open to fishing and general use. Fish were surveyed by trophic groups: two 45-minute timed swims for top predators; 50 × 10 m wide transects for mid-ranking predators and mobile herbivores; and 50 × 2 m wide transects for territorial grazers. Biomass was calculated using length-weight relationships. Duration of protection in no-take and no-entry zones ranged from 11–27 years.

(1) Mann B.Q., Cowley P.D. & Fennessy S.T. (2015) Movement patterns of surf–zone fish species in a subtropical marine protected area on the east coast of South Africa. *African Journal of Marine Science*, 37, 99–114.

(2) Tunley K.L., Attwood C.G., Moloney C.L. & Fairhurst L. (2009) Variation in population structure and life-history parameters of steentjies *Spondyliosoma emarginatum*: effects of exploitation and biogeography. *African Journal of Marine Science*, 31, 133–143.

(3) La Mesa G., Molinari A., Bava S., Finoia M. G., Cattaneo-Vietti R. & Tunesi L. (2011) Gradients of abundance of sea breams across the boundaries of a Mediterranean marine protected area. *Fisheries Research*, 111, 24–30.

(4) Maggs J.Q., Mann B.Q. & Cowley P.D. (2013) Contribution of a large no-take zone to the management of vulnerable reef fishes in the South-West Indian Ocean. *Fisheries Research*, 144, 38–47.
(5) Maggs J.Q., Mann B.Q. & Cowley P.D. (2013) Reef fish display station-keeping and ranging behaviour in the Pondoland Marine Protected Area on the east coast of South Africa. *African Journal of Marine Science*, 35, 183–193.
(6) Rizzari J.R., Bergseth B.J. & Frisch A.J. (2015) Impact of conservation areas on trophic interactions between apex predators and herbivores on coral reefs. *Conservation Biology*, 29, 418–429.
(7) Bobiles R.U., Soliman V.S. & Nakamura Y. (2016) Partially protected marine area renders non-fishery benefits amidst high fishing pressure: A case study from eastern Philippines. *Regional Studies in Marine Science*, 3, 225–233.
(8) Casey J.M., Baird A., Brandl S.J., Hoogenboom M.O., Rizzari J.R, Frisch A.J., Mirbach C.E. & Connolly S.R. (2017) A test of trophic cascade theory: fish and benthic assemblages across a predator density gradient on coral reefs. *Oecologia*, 183, 161–175.

2.18 Restrict fishing activity (types unspecified) in a marine protected area

- **Two studies** examined the effects of restricting (unspecified) fishing activity in a marine protected area on marine fish populations. One study was global[1] and the other was in the Indian Ocean[2] (Tanzania).

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study)**: One global review[1] reported that of 11 studies showing effects of protection from restricting fishing activity in marine reserves, one found higher fish species richness inside reserves compared to non-protected fished areas.

POPULATION RESPONSE (2 STUDIES)

- **Survival (1 study):** One site comparison study in the Indian Ocean[2] found that survival was higher for blackspot snapper inside a marine park with unspecified fishing restrictions and low fishing intensity compared to more intensively fished areas outside.
- **Abundance (1 study)**: One global review[1] reported that 10 of 11 studies showing effects of protection from restricting fishing activity in marine reserves found higher abundance of fish inside the areas compared to areas without fishing restrictions.
- **Condition (2 studies):** One site comparison study in the Indian Ocean[2] found that blackspot snapper inside a marine park with unspecified fishing restrictions and low fishing intensity were of larger average size, reached older ages, but did not have different growth rates compared to more intensively fished areas outside the park. One global review[1] reported that five out of 11 studies showing effects of protection from restricting fishing activity in marine reserves found fish were larger inside reserves compared to non-protected areas without fishing restrictions.

BEHAVIOUR (0 STUDIES)

Background

Marine Protected Areas are designations for marine sites in which fish (among other marine animals and habitats) conservation can be promoted through management of the fishing and other human activities that take place within them. Restricting fishing activity inside a protected area should reduce the overall fishing mortality and disturbance to fish habitats. In studies where the exact fishing types that are regulated inside a protected area are not reported, it may still be expected that fish populations may respond to an overall reduction in fishing pressure and exploitation.

Evidence for similar interventions relating to prohibiting human activity, including fishing, in marine protected areas is summarized under *'Cease or prohibit all types of fishing in a marine protected area'*, *'Cease or prohibit all fishing activity in a marine protected area with limited exceptions*' and '*Control human activity in a marine protected area with a zonation system of restrictions*'.

A review in 1994 of 11 studies published between 1982–1994 on the effects of restricting fishing activity (types unspecified) on fish in marine reserves across the world (1) reported that 10 studies found higher fish abundances, five found fish size was larger and one found a greater number of fish species, inside compared to outside reserves. Overall, 45–73% of fish species surveyed were more abundant inside reserves compared to outside (where reported). In addition, in one reserve 18 months after protection from fishing had failed, abundance (catch rates) decreased by 57% (hook and line), 58% (gill net) and 33% (trap fishing). Twenty studies of reserves that were considered to provide some form of real protection from fishing (for both finfish and shell fisheries) were reviewed (search method was not reported) and examples discussed mainly from sub-tropical and temperate marine reserves. A total of 11 studies reported effects on fish species. Studies were carried out in the Pacific, Atlantic and Indian Oceans and the Mediterranean Sea.

A site comparison study in 1999–2001 at four patch reef sites in the Indian Ocean, Tanzania (2) found that inside a marine park with low fishing intensity, blackspot snapper *Lutjanus fulviflamma* were larger and older and had lower overall and fishing mortality rates, but no difference in growth rates than snapper in adjacent more intensively fished areas. Average size of snapper in low fishing areas was larger (211 mm) than the heavily fished areas (155 mm). The maximum snapper age was higher in low fishing intensity areas (low: 18 yrs, intensive: 8 yrs), and most individuals were 6–10 years old compared to mainly 2 and 4 year-olds in intensively fished areas. In the marine park, overall mortality (low: 0.55/yr, intensive: 1.64/yr) and fishing mortality (low: 0.18/yr, intensive: 1.37/yr) rates were lower compared to intensively fished areas. There were no significant differences in growth rates between all four sites (data given as growth parameters). Mafia Island Marine Park (822 km^2) was established in 1995 as a multiple-use area and, although fishing was permitted in the park (details not reported), fishing intensity was significantly lower than in adjacent areas outside. Surveillance and enforcement were carried out within the park and action taken against illegal fishing. Data were collected from two sampling sites within the park with low fishing intensity (3.6–5.1 fishermen/km^2) and two outside sites with high fishing intensity (6.4–8.6 fishermen/km2). From May 1999 to April 2001, monthly samples of snapper were collected from traditional vessels using seine nets. Snapper numbers, lengths and weights were recorded and the ear stones (otoliths) removed for determination of age and growth.

(1) Rowley R.J. (1994) Marine reserves in fisheries management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 4, 233–254.

(2) Kamukuru A.T., Hecht T. & Mgaya Y.D. (2005) Effects of exploitation on age, growth and mortality of the blackspot snapper, *Lutjanus fulviflamma*, at Mafia Island, Tanzania. *Fisheries Management and Ecology*, 12, 45–55.

Reduce Unwanted Catch and Discards, and Improve Survival of Returned or Escaped Fish

Deployment of fishing gear and mode of operation

2.19 Deploy fishing gear at selected depths to avoid unwanted species

- **Five studies** examined the effect of deploying fishing gear at selected depths to avoid unwanted species on marine fish populations. Three studies were in the Atlantic Ocean[2,3,4] (Florida, Brazil, Canary Islands), and one study was in each of the Pacific Ocean[1] (Hawaii) and the Tasman Sea[5] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (5 STUDIES)

- **Reduction of unwanted catch (5 studies):** Four of five replicated studies (three controlled, one paired and controlled) in the Pacific Ocean[1], Atlantic Ocean[2,3,4] and the Tasman Sea[5] found that deploying fishing gear (longlines[1,2,3], handlines[5] and traps[4]) at selected depths, including above the seabed instead of on it, reduced the unwanted catches of five of 17 fish species[1], three of eight shark/ray species[3], non-commercially targeted fish species[4] and Harrison's dogfish[5], compared to depths usually fished. The other study[2] found that different shark species were hooked at different depths in the water column during bottom-set longlining deployments.

Background

The depths fish are found throughout the water column depends not only on the species and their preferred habitat, but also on factors such as behaviour (e.g. for feeding or spawning) and age structure. It is also highly influenced by environmental conditions like water temperature and salinity, among others, and may change over short timescales, such as different times of the day. Different fishing gears exploit the known depth distributions of fish and are deployed either on the seabed or at specific depths in the water column to maximise catches of the desired fish (aided by sonar technology in many cases). Conversely, this knowledge may also be used to avoid the capture of fish, potentially rare or threatened species and commercial unwanted species or sizes.

Evidence for similar interventions is summarized under *'Deployment of fishing gear and mode of operation - Deploy fishing gear at selected times (day/night) to avoid unwanted species'* and *'Selectively avoid the capture of unwanted fish based on temperature distribution'*.

A replicated, controlled study in 2006 of pelagic waters in the Pacific Ocean around Hawaii (1) found that longlines deployed at selected depths (deeper) reduced catches of five out of 17 unwanted fish species compared to conventional, shallower-set longlines. Catch rates of five out of 17 unwanted species were lower on sets using deeper longlines compared to shallower longlines: wahoo *Acanthocybium solandri* (0.4 vs 1.2 fish/set), dolphinfish *Coryphaena hippurus* (1.3 vs 3.8 fish/set), blue marlin *Makaira nigricans* (0.1 vs 0.4 fish/set), striped marlin *Kajikia audax* (0.5 vs 1.5 fish/set) and shortbill spearfish *Tetrapturus angustirostris* (0.1 vs 0.6 fish/set). Catch rates of most other unwanted fish (11 out of 17 species – see paper for species individual data) were similar between longline depths, including the target commercial species bigeye tuna *Thunnus obesus* (5.7 vs 4.7 fish/set). One unwanted species, sickle pomfret *Taractichthys steindachneri*, was caught more frequently with deeper longlines (3.5 fish/set) than shallower longlines (2.0 fish/set). A total of 90 longline sets (2,000 hooks/set) were deployed from a vessel fishing out of Honolulu, Hawaii, in June-December 2006. Forty-five sets were modified using 3 kg weighted lines to keep all hooks at depths of 103 m at either end to 248 m in the middle. The other 45 were conventional sets with hooks at depths between 44–211 m. The vessel used deeper and shallower sets on alternate days.

A replicated study in 2005–2007 of fishing grounds in the North West Atlantic Ocean off Florida, USA (2) found that different species of sharks were hooked on bottom-set longline gear at different water depths. Sandbar sharks *Carcharhinus plumbeus* were only caught at depths >20 m (21–40 m: 43, 41–60 m: 50, >60 m: 12 sharks/10,000 hook hours). Blacktip sharks *Carcharhinus limbatus* were caught less frequently at depths <60 m (<20 m: 41, 21–40 m: 18, 41–60 m: 15, >60 m: 91 sharks/10,000 hook hours). Three other shark species were most frequently caught between 41 and 60 m depths: tiger shark *Galeocerdo cuvier* (<20 m: 3, 21–40 m: 8, 41–60 m: 33, >60 m: 28 sharks/10,000 hook hours), Atlantic sharpnose *Rhizoprionodon terraenovae* (<20 m: 49, 21–40 m: 13, 41–60 m: 43, >60 m: 13 sharks/10,000 hook hours) and blacknose *Carcharhinus acronotus* (<20 m: 15, 21–40 m: 10, 41–60 m: 34, >60 m: 6 sharks/10,000 hook hours). Fifty-five gear deployments were undertaken, each with 8–10 km of longline with 250 branch lines set with 18/0 circle hooks with a 10° offset, deployed either overnight for 6–10 h or for 4–6 h during the day.

A replicated, paired, controlled study in 2004–2005 in 608 shallow, coastal water sites in the West Atlantic Ocean off Recife, Brazil (3) found that longline hooks deployed in the water column (pelagic) caught fewer sharks and rays (*Elasmobranchii*) of three of eight species, compared to hooks set close to the seabed (demersal). Fewer numbers were caught on pelagic hooks than demersal for the three most captured species: southern stingray *Dasyatis Americana* (pelagic: 0.5 fish/1,000 hooks, demersal: 3.3 fish/1,000 hooks; n=43)*;* blacknose shark *Carcharhinus acronotus* (pelagic: 0.8 fish/1,000 hooks, demersal: 2.9 fish/1,000 hooks; n=41); and nurse shark *Ginglymostoma cirratum* (pelagic: 0.1 fish/1,000 hooks, demersal: 1.2 fish/1,000 hooks; n=14). A further five species were caught infrequently on pelagic hooks only (tiger shark, *Galeocerdo cuvier*, manta ray, *Manta birostris,* bull shark, *Carcharhinus leucas,* scalloped hammerhead, *Sphyrna lewini,* blacktip shark, *Carcharhinus limbatus*). Catch rates were so low they were not significantly different between pelagic and demersal hooks (pelagic: 0.1–0.4 fish/1,000 hooks, demersal: 0 fish/1,000 hooks; n=11). In September 2004 to August 2005, a total of 384 longline sets with 100 J-shaped hooks each were deployed, half close to the seabed and the other half suspended in mid-water, in depths of 8–14 m, 1–3 km from the coast.

Hooks were baited with moray-eel *Gymnothorax* sp.. Sixty-two sharks and 46 rays were caught in total.

A replicated, controlled study in 2003–2004 of seabed and near seabed in the Atlantic Ocean off the Canary Islands, Spain (4) reported that shrimp traps fished above the seabed (semi-floating) caught less unwanted fish catch (non-commercially targeted or discarded) catch than traditional bottom traps set on the seabed, and the difference decreased with overall depth. Data were not statistically tested. At 100–400 m depths, semi-floating traps caught 18 unwanted species of fish at catch rates between <0.1–858.9 g/trap/day, and bottom traps caught eight species at <0.1–24.9 g/trap/day. Between 401–800 m depth, semi-floating traps caught eight unwanted fish species (<0.1–2,241.0 g/trap/day) while bottom traps caught four species (0.4–140.6 g/trap/day). At the deepest depths (801–1,130 m), semi-floating traps caught five unwanted fish species (<0.1–186.4 g/trap/day) and four were caught in bottom traps (0.5–41.9 g/trap/day). At all but the deepest depths, conger eels *Conger conger* accounted for a large proportion of the unwanted catch in bottom traps and in semi-floating traps at the intermediate depths (see paper for species individual data). Target shrimp *Plesionika* spp. catches between floating and bottom traps varied with species and depth (see paper for data). Four research surveys were done around the Canary Islands in 2003–2004 at depths of 100–1,300 m. Two types of traps were used to target shrimp: semi-floating traps of plastic mesh (20 ×15 mm) covering a conical cylinder (56 × 57 cm), and bottom traps made of wire mesh (19 × 19 mm) and an iron rectangular frame (100 × 100 × 50 cm). Semi-floated traps were set in groups of 75 traps, 15 m apart and 2 m above the seabed (total 1,971). Bottom traps were deployed in lines of 10 traps, 50 m apart (total 487). All traps were deployed in daylight hours and baited with mackerel *Scomber colias*.

A replicated, controlled study (year not stated) of two seamount marine reserves in the Tasman Sea, Australia (5) found that fishing at specific depths and times reduced unwanted catch of endangered Harrison's dogfish *Centrophorus harrissoni* in a restricted commercial blue-eye trevalla *Hyperoglyphe antarctica* handline fishery. Catch rates were lower (0 fish/100 hooks) on seamounts defined as being 'non-dogfish habitat', combining selected depths (280–550 m) and time of day (daytime) compared to 'dogfish habitat' (280–550 m, night: 0.1 fish/100 hooks; 550–830 m, day: 0.4 fish/100 hooks). Catches of trevalla were highly variable but appeared slightly lower in the 'non-dogfish' habitat' compared to the 'dogfish habitat' (non-dogfish: 8.2–34.3 fish/100 hooks, dogfish: 9.1–48.9 fish/100 hooks; data not tested for significance). Hydraulically powered handlines with 18 hooks each were deployed during 10 vessel trips 4–5 days long during the day in mid-water (280–550 m) and deep-water (550–830 m), and at night in mid-water. In 'non-dogfish habitat' 1,036 handline deployments were carried out and 407 deployments were in 'dogfish habitat'. Handlines were deployed at randomly selected positions and hauled after 5–10 minutes or until it was felt several fish had been hooked. Details of when the study took place were not reported. Fish were identified and counted.

(1) Beverly S., Curran D., Musyl M. & Molony B. (2009) Effects of eliminating shallow hooks from tuna longline sets on target and non-target species in the Hawaii-based pelagic tuna fishery. *Fisheries Research*, 96, 281–288.

(2) Morgan A. & Carlson J. K. (2010) Capture time, size and hooking mortality of bottom longline-caught sharks. *Fisheries Research*, 101, 32–37.

(3) Afonso A.S., Hazin F.H.V., Carvalho F., Pacheco J.C., Hazin H., Kerstetter D.W., Murie D. & Burgess G.H. (2011) Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research,* 108, 336–343.

(4) Arrasate-López M., Tuset V.M., Santana J.I., García-Mederos A., Ayza O. & González J.A. (2012) Fishing methods for sustainable shrimp fisheries in the Canary Islands (North-West Africa). *African Journal of Marine Science*, 34, 331–339.
(5) Williams A., Upston J., Green M. & Graham K. (2016) Selective commercial line fishing and biodiversity conservation co-exist on seamounts in a deepwater marine reserve. *Fisheries Research*, 183, 617–624.

2.20 Deploy fishing gear at selected times (day/night) to avoid unwanted species

- **Two studies** examined the effect of deploying fishing gear at selected times to avoid unwanted species on marine fish populations. Both studies were in the South Pacific Ocean[1,2] (Lake Wooloweyah, Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (2 studies):** One of two replicated, controlled studies in the South Pacific Ocean[1,2] found that trawling for prawns during the day reduced the overall catch of unwanted fish by number, but not weight, compared to usual night trawling, and the effect differed by species[1]. The other study[2] found that powered handlining in the day avoided catches of Harrison's dogfish at shallower, but not deeper seamounts, compared to the night.

Background

Many marine species undertake daily vertical migrations through the water column during day/night cycles, influenced by factors such as temperature, light levels, and prey availability. Some shark species, for example, swim closer to the sea surface at night than during the day (Bromhead *et al.* 2012). There is also evidence that in sufficient levels of light some fish are better able to detect, and thus better avoid, approaching trawl gear (Glass & Wardle 1989) or escape from parts of the net after entering it (Gabr *et al*. 2007). The timing of setting and hauling gear can, therefore, affect catch rates (Gilman *et al.* 2008), so fishing at a specific time of day/night may help to avoid unwanted or threatened fish species whose distribution or behaviour decreases the likelihood of capture.

Evidence for similar interventions is summarized under *'Deployment of fishing gear and mode of operation - Deploy fishing gear at selected depths to avoid unwanted species'* and *'Selectively avoid the capture of unwanted fish based on temperature distribution'.*

Bromhead D., Clarke S., Hoyle S., Muller B., Sharples P. & Harley S. (2012) Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications. *Journal of Fish Biology*, 80, 1870–1894.
Gabr M., Fujimori Y., Shimizu S. & Miura T. (2007) Behaviour analysis of undersized fish escaping through square meshes and separating grids in simulated trawling experiment. *Fisheries Research*, 85, 112–121.
Gilman E., Clarke S., Brothers N., Alfaro-Shigueto J., Mandelman J., Mangel J., Petersen S., Piovano S., Thomson N., Dalzell P., Donoso M., Goren M. & Werner T. (2008) Shark interactions in pelagic longline fisheries. *Marine Policy*, 32, 1–18.

Glass C.W. & Wardle C.S. (1989) Comparison of the reactions of fish to a trawl gear, at high and low light intensities. *Fisheries Research*, 7, 249–266.

A replicated, controlled study in 2014 at an estuary/lagoon site in Lake Wooloweyah, Australia (1) found that trawling for prawns during the day decreased the number, but not weight, of unwanted fish overall compared to the usual practice of trawling during the night, and the effect varied between species. Overall catch rate of unwanted fish by number was lower during the day compared to the night (day: 57–72 fish/ha, night: 107–109 fish/ha), but by weight catch rate was the same (both 1 kg/ha). Trawl deployments during the day reduced the catches of three of seven individual fish species (day: 2–7 fish/ha, night: 5–34 fish/ha), but catch rates were higher than at night for three others (day: 2–65, night: <1–35 fish/ha) and the same for one (2 fish/ha). See original paper for individual species data. Number and weight of commercial target school prawns *Metapenaeus macleaya* were the same for both night and day deployments (number: 3,272–3,958 prawn/ha, weight: 7–9 kg/ha). In March and April 2014, identical trawl nets were compared by trawling for 45 minutes during six days and four nights. Two types of lengths with different wing and body tapers were tested during 44 paired deployments.

A replicated, controlled study (year not stated) of two seamount marine reserves in the South Pacific Ocean 200 km off New South Wales, Australia (2) found that selective fishing at specific times and depths avoided the unwanted catch of Harisson's dogfish *Centrophorus harrissoni* in a restricted commercial blue-eye trevalla *Hyperoglyphe antarctica* handline fishery. Across areas, catch rates were lower (0 fish/100 hooks) during the day at seamounts 280–550 m deep (defined as being 'non-dogfish habitat'), but not at the deeper seamounts (0.4 fish/100 hooks), compared to seamounts at 280–550 m during the night (0.1 fish/100 hooks), both of the latter defined as 'dogfish habitat'. Catches of trevalla were highly variable but appeared slightly lower in the 'non-dogfish' habitat' compared to the 'dogfish habitat' (non-dogfish: 8.2–34.3 fish/100 hooks, dogfish: 9.1–48.9 fish/100 hooks; data not tested for significance). Hydraulically powered handlines with 18 hooks each were deployed during 10 vessel trips 4-5 days long during the day in mid-water (depths) and deep-water (depths), and at night in mid-water. In 'other habitat' 1,036 handline deployments were carried out and 407 in 'dogfish habitat'. Handlines were deployed at randomly selected positions and hauled after 5-10 minutes or until it was felt several fish had been hooked. Details of when the study took place were not provided. Fish were identified and counted.

(1) Broadhurst M. K., Sterling D. J. & Millar R. B. (2015) Effects of diel period and diurnal cloud cover on the species selection of short and long penaeid trawls. *Fisheries Research,* 170, 144–151.
(2) Williams A., Upston J., Green M. & Graham K. (2016) Selective commercial line fishing and biodiversity conservation co-exist on seamounts in a deepwater marine reserve. *Fisheries Research*, 183, 617–624.

2.21 Selectively avoid the capture of unwanted fish based on temperature distribution

- We found no studies that evaluated the effects of selectively avoiding the capture of fish by their temperature distributions on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Multispecies fisheries are often managed on a quota system whereby fishers must avoid vulnerable or weak stocks while trying to maintain catches of stronger stocks. One way to do this may be to selectively avoid fish based on differences in distribution between non-target and target species caused by oceanographic features such as temperature. Temperature influences the distribution and abundance of fish seasonally, not only at different geographical locations, but also throughout the water column at different depths. Based on this, Dunn *et al. 2016* suggested that unwanted Atlantic cod could largely be avoided in the spring in the North Atlantic Ocean, when their distribution differed from 38–54% of other species.

Evidence for similar interventions is summarized under *'Deployment of fishing gear and mode of operation - Deploy fishing gear at selected times (day/night) to avoid unwanted species'* and *'Deploy fishing gear at selected depths to avoid unwanted species'.*

Dunn D.C., Moxley J.H., & Halpin P.N. (2016) Temperature-based targeting in a multispecies fishery under climate chance. *Fisheries Oceanography,* 25, 105–118.

2.22 Reduce duration of fishing gear deployments

- **Four studies** examined the effects of reducing the duration of time that fishing gear is deployed in the water on marine fish populations. Two studies were in the North Sea[2,4]. One study was in the Atlantic Ocean[3] (USA) and one was in both the Barents Sea and Atlantic Ocean[1] (Norway/USA).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** Two replicated, controlled studies in the North Sea[2,4] found that survival of unwanted plaice and/or sole released after capture in beam or pulse trawls was higher after shorter duration trawl deployments, but that the opposite was true for plaice captured in otter trawls, over tow durations of between one and two hours.

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (1 study):** One of two replicated studies (one paired and controlled) in the Barents Sea/Atlantic Ocean[1] and the Atlantic Ocean[3] found that catch rates of unwanted sharks caught in longline gear decreased with decreasing time the gear was deployed in the water, over durations of up to 10 hours[3]. The other study[1] found that shorter tow durations caught similar amounts of small haddock, but more small cod, than longer durations, in bottom trawls fished for between five minutes and one hour.
- **Improved size-selectivity of fishing gear (1 study):** One replicated, paired, controlled study in the Barents Sea/Atlantic Ocean[1] found that varying bottom trawl fishing durations between five minutes and two hours had no effect on the size-selectivity of Atlantic cod, haddock or long rough dab.

Background

The length of time for which fishing gear is deployed, also known as soaking time, can affect the amount of unwanted species caught, catch efficiency, and the condition and survival of released unwanted catch. Shorter gear deployments reduce the amount of time that the gear is in the water and consequently can minimise potential interactions with the wider ecosystem. In longline fisheries, for example, catch rates are initially high after gear deployment, but then decrease (Løkkeborg & Pina 1996), and shorter gear deployments may reduce the amount of unwanted catch. Furthermore, unwanted catch that remains hooked for a shorter amount of time may be more likely to survive after being released. In towed gears such as trawls, shorter gear deployments can reduce the physiological effects of stress and crowding during capture in the gear on unwanted catch, again potentially increasing post-release survival (Heard *et al*. 2014).

Evidence for similar interventions is summarized under *'Deployment of fishing gear and mode of operation - Reduce duration of fishing gear deployments'* and *'Reduce the hauling speed of a trawl net'.* See also *'Handling of Catch'*.

Heard M., Van Rijn J.A., Reina R.D. & Huveneers C. (2014) Impacts of crowding, trawl duration and air exposure on the physiology of stingarees (family: Urolophidae). *Conservation Physiology*, 2, 1–14.

Løkkeborg S. & Pina T. (1997) Effects of setting time, setting direction and soak time on longline catch rates. *Fisheries Research*, 32, 213–222.

A replicated, paired, controlled study in 1985–1989 in three areas of seabed in the Barents Sea and Atlantic Ocean off Norway and USA (1) found that shorter bottom trawl tow durations did not improve the size-selectivity of Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus* and long rough dab *Hippoglossoides platessoides*, and more small cod but not haddock were caught, for different tow durations between 5 min to 2 h. Across all three trials, the average fish length was similar between tow durations, for cod (trials 1 & 2, 15 min: 26–32 cm, 30 min: 29–32 cm, 60 min: 32–35 cm; trial 3, 5 min: 50 cm, 30 min: 50 cm), haddock (trials 1 & 2, 15 min: 18–33 cm, 30 min: 17–33 cm, 60 min: 19–32 cm, 120 min 33 cm; trial 3, 5 min: 27 cm, 30 min: 27 cm, 120 min: 33 cm) and long rough dab (trials 1 & 2 only, 15 min: 24–26 cm, 30 min: 24–25 cm, 60 min: 32–35 cm). In addition, in two of two trials there were no differences in catch rates of small haddock between tow durations (5–60 min), however, the catch rates of small cod increased with decreasing shorter tow durations (see original paper for data). Two trials (one and two) were done in the Barents Sea in October 1988 (nine parallel deployments by two vessels: three each of 15, 30 and 60 min) and February 1989 (24 deployments: 16 × 5 mins and 8 × 30 mins). Additional data from a trial on the Georges Bank in January 1985 (trial three)was also analysed (64 deployments: two each of 15, 30, 60 and 120 min at eight stations). Tow durations were based on the standard tow duration for trawl surveys (from 30 min to 2 h).

A replicated, controlled study in 1972–1982 in an area of seabed in the North Sea (2) found that survival of sole *Solea solea* and plaice *Pleuronectes platessa* discards was higher in shorter deployments of beam trawls, but not of plaice in otter trawls, for tow durations between one and two hours. For beam trawls, survival of sole and plaice 84 hours after capture was higher for 60-minute deployments (sole: 21%, plaice: 19%) compared to 120-minute deployments (sole: 7%, plaice: 10%). For otter trawls, survival of plaice 84 hours after capture was lower for 60-minute deployments (11%) compared to 100–105-minute deployments (33%). Commercial fishing vessels carried out 12 × 60-minute and 15 × 120-minute-long beam trawl deployments between November 1979 and December

1982 in the North Sea (location not reported). Gear was towed at 5–5.5 knots. A research vessel carried out 3 × 60-minute and 4 × 100–105-minute-long deployments using an otter trawl between November 1972 and February 1975 towed at 3.5 knots (North Sea, exact location not reported). Sole of 20–28 cm length and plaice of 20–30 cm length were removed from each catch onboard and placed in seawater tanks (40 × 60 × 12 cm). Survival was monitored every 12 hours until all fish had died or the end of the survey.

A replicated study in 2005–2007 of a fished area of seabed in the Atlantic Ocean off Florida, USA (3) found that catch rates of unwanted sharks (Chondrichthyes) on bottom-set longlines were lower at shorter times the gear had been in the water, and varied between species with depth, at fishing durations of up 10 hours. For the four main species, the overall probability of capture (hook being bitten) increased most from 5 hours after the start of gear deployment compared to the first 5 hours of the sets, and for individual species the average amount of time hooks were in the water prior to being bitten was 4 hours for sandbar *Carcharhinus plumbeus* and blacknose sharks *Carcharhinus acronotus*, 5 hours for blacktip sharks *Carcharhinus limbatus*, and 9 hours for bull sharks *Carcharhinus leucas*, respectively (data reported as statistical model results). Sandbar sharks were only caught at depths >20 m (21–40 m: 43, 41–60 m: 50, >60 m: 12 sharks/10,000 hook hours). Blacktip sharks were caught less frequently at depths <60 m (<20 m: 41, 21–40 m: 18, 41–60 m: 15, >60 m: 91 sharks/10,000 hook hours). Blacknose sharks and two other shark species were most frequently caught between 41 and 60 m depths: blacknose (<20 m: 15, 21–40 m: 10, 41–60 m: 34, >60 m: 6 sharks/10,000 hook hours), tiger shark *Galeocerdo cuvier* (<20 m: 3, 21–40 m: 8, 41–60 m: 33, >60 m: 28 sharks/10,000 hook hours), Atlantic sharpnose *Rhizoprionodon terraenovae* (<20 m: 49, 21–40 m: 13, 41–60 m: 43, >60 m: 13 sharks/10,000 hook hours). Fifty-five longline deployments were undertaken (8–10 km of longline, 18/0 circle hooks with a 10° offset). Longlines were deployed either overnight for 6–10 h or for 4–6 h during the day. Hook timers on each hook recorded shark capture times.

A replicated, controlled study in 2014–2015 on an area of seabed in the southern North Sea, Netherlands and UK (4) found that reducing the length of the hauls using a pulse trawl increased survival of plaice *Pleuronectes platessa* compared to standard length hauls, over haul durations of 60–130 minutes. When haul duration was 60–70 minutes, more plaice survived compared to standard 100–130 minute hauls (data not reported). Two fishing vessels were used to carry out three surveys with two short (60–70 minute) hauls and four surveys with standard (100–130 minute) hauls using standard fishing operations with a pulse trawl, between November 2014 and September 2015. After sorting the catch on deck, 40 fish below commercial size from each haul were kept in seawater tanks and fed every 24 hours. Survival was monitored daily for at least 21 days.

(1) Godø O.R., Pennington M. & Vølstad J.H. (1990) Effect of tow duration on length composition of trawl catches. *Fisheries Research*, 9, 165–179.

(2) van Beek F.A., van Leeuwen P.I. & Rijnsdorp A.D. (1990) On the survival of plaice and sole discards in the otter-trawl and beam-trawl fisheries in the North Sea. *Netherlands Journal of Sea Research,* 26, 151–160.

(3) Morgan A. & Carlson, J.K. (2010) Capture time, size and hooking mortality of bottom longline-caught sharks. *Fisheries Research*, 101, 32–37.

(4) van der Reijden K.J., Molenaar P., Chen C., Uhlmann S.S., Goudswaard P.C. & Van Marlen B. (2017) Survival of undersized plaice (*Pleuronectes platessa*), sole (*Solea solea*), and dab (*Limanda limanda*) in North Sea pulse-trawl fisheries. *ICES Journal of Marine Science,* 74, 1672–1680.

2.23 Change the towing speed of a trawl net

- **One study** examined the effect of changing the towing speed of a trawl net on catch of marine fish. The study was in the North Sea[1] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Improved size-selectivity of fishing gear (1 study):** One replicated, paired study in the North Sea[1] found that changing the towing speed of a bottom trawl net did not increase the size selectivity of small cod and haddock.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Fish entering the net will either be retained by it or may escape through the gaps in the mesh of the trawl netting during fishing. Many factors can influence the likelihood of a fish being caught or escaping from a trawl (termed selectivity or efficiency) including species, size of fish, time of day, trawl configuration and towing speed. The towing speed of a net may affect the size and shape of the meshes through which fish may escape. But it may also affect how likely a fish is to avoid entering the net in the first place. Fish behaviour differs on encountering different trawl nets (Krag *et al*. 2014) and the towing speed of the net may further change the ability of fish to escape in response to the altered hydrodynamics that may require a different swimming behaviour. Fish have been seen to actively escape trawl nets by accelerating in bursts or changing direction, or, more commonly, escaping in response to contact with the net (Jones *et al.* 2008). Depending on the species, a faster or slower towing speed may allow more fish to escape.

Evidence for similar interventions is summarized under *'Deployment of fishing gear and mode of operation - Change the towing speed of a trawl net'* and *'Reduce the hauling speed of a trawl net'.* See also *'Handling of Catch'*.

Krag L.A., Herrmann B. & Karlsen J.D. (2014) Inferring Fish Escape Behaviour in Trawls Based on Catch Comparison Data: Model Development and Evaluation Based on Data from Skagerrak, Denmark. *PLoS ONE*, 9, e88819.

Jones E., Summerbell K. & O'Neill F. (2008) The influence of towing speed and fish density on the behaviour of haddock in a trawl cod-end. *Fisheries Research,* 98, 166–174.

A replicated, paired study in 1995 of one area of seabed in the North Sea off southern Norway (1) found that changing the towing speed of a bottom trawl net did not improve the size selectivity of unwanted small cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*. Across both vessels and net sizes, the length at which fish had a 50% chance of escaping was similar between two towing speed ranges for both cod (slower: 30–34 cm, faster: 30–34 cm) and haddock (slower: 28–32, faster: 28–33). In April 1995, trawl towing speed was tested on two fishing vessels (20 deployments each), fishing at the same time on the same fishing grounds (exact location not reported). Vessels had different sizes of bottom trawl nets, one a standard size and one a scaled-down size but both had identical codends (see paper for specifications). For the larger net, catches were analysed for towing speeds above and below 3.0 m/s and for the smaller net <3.5 versus >3.5 m/s. Fish retained by the larger net were sampled in twin codends, one with the test net and one with a small mesh to sample all sizes of fish. On the smaller net a cover was attached to the codend to collect fish escaping through the meshes. All codend and cover catches were sorted and weighed by species and total lengths recorded.

(1) Dahm E., Wienbeck H., West C.W., Valdemarsen J.W. & O'Neill F.G. (2002) On the influence of towing speed and gear size on the selective properties of bottom trawls. *Fisheries Research*, 55, 103–119.

2.24 Reduce the hauling speed of a trawl net

- We found no studies that evaluated the effects of reducing the hauling speed of a trawl net on marine fish populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Hauling a trawl net back to the surface at a slow speed might allow fish to swim forward and escape the net, or if the trawl is equipped with a catch reduction device it might further encourage escape opportunities (Eayrs 2007). Whilst this may reduce the catch of unwanted fish, there is an increased potential for commercially valuable fish to also escape the trawl if hauling speed is too slow. Hauling at a slower speed may also reduce fish stress and physical damage which may result in higher survival if discarded.

Evidence for similar interventions is summarized under *'Deployment of fishing gear and mode of operation - Reduce duration of fishing gear deployments'* and *'Change the towing speed of a trawl net'.* See also *'Handling of Catch'*.

Eayrs S. (2007) A guide to bycatch reduction in tropical shrimp-trawl fisheries. Revised edition. Rome, FAO. 108p.

Handling of catch

2.25 Use a different method to sort or bring catch onboard

- We found no studies that evaluated the effects of using different methods to sort or bring catches onboard vessels on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The process of fish being lifted out of the water in fishing nets and on to a vessel for sorting can create extreme stress (Ashley 2006). In trawl nets there is also an increased likelihood of crush or puncture injuries under the weight of the catch. In addition, depending on the duration of time exposed during the catch sorting process , fish survival is decreased, not only due to factors such as oxygen deprivation, but also to the drying out of the fishes' protective layer. Using different methods to move and sort fish (e.g. using water) may help improve the survival of discarded fish that after sorting are returned to the sea, by minimising air exposure and overall damage, including disruption to their mucus layer and scales (Hürlimann *et al.* 2014). One potential sorting method to reduce discard mortality, using a water-filled sorting tray instead of a conventional dry tray, led to fewer deaths of discarded fish during longer sorting times (Broadhurst *et al*. 2008).

For related interventions, see *'Handling of catch'*.

Ashley P.J. (2007) Fish welfare: current issues in aquaculture. *Applied Animal Behaviour Science*, 104, 199–235.

Broadhurst M.K., Uhlmann S.S. & Millar R.B. (2008) Reducing discard mortality in an estuarine trawl fishery. *Journal of Experimental Marine Biology & Ecology*, 364, 54–61.

Hürlimann R., Laan R., Vissia S., Willemsma A. & Zagenia F. (2014) Welfare of wild caught plaice (*Pleuronectes platessa*) An inventory how current practices in fisheries may affect welfare of plaice and possible indicators thereof. MSc thesis. Wageningen University, Netherlands.

2.26 Reduce the duration of exposure to air of captured fish before release

- **Three studies** examined the effect of reducing the duration of exposure of fish to air on marine fish populations. One study was in each of the Bay of Biscay[1] (Spain), Gulf of Alaska[2] (Canada) and Coral Sea[3] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (1 study):** One replicated study in the Bay of Biscay[1] found that reducing air exposure before release did not increase the survival of small-spotted catshark caught during commercial trawling.
- **Condition (1 study):** One replicated study in the Gulf of Alaska[2] found that shorter durations of air exposure before release improved the physical condition and reduced the amount of injury to discarded chum salmon caught in purse seine nets.

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One study in the Coral Sea[3] found that minimal exposure to air and handling resulted in improved overall behaviour after release (activity and ability to return to reef) of reef fish, compared to fish exposed to air and handling for longer duration.

Background

In all types of fishing activity, fish are exposed to the air when the fishing gear they have been captured with is retrieved from the water. In commercial fisheries, the duration of air exposure can vary widely and depends on fishing method, the amount and type of catch and the processes used to sort it. When fish leave the water the surface area of their gills is drastically reduced and oxygen uptake into the bloodstream virtually stops (Ferguson & Tufts 1992). They are likely to suffer external injury as well as internal damage as a response to the acute stress. A fish will ultimately die if left out of water. However, some fish species are more tolerant to exposure than others and can survive for a relatively long time in air. Reducing the length of time fish are exposed to air before being returned to the water may influence survival by reducing physical injury and damage caused by lack of oxygen. Normal gill function returns when live fish are returned to water.

For related interventions, see *'Handling of catch'*.

Ferguson R.A. & Tufts B.L. (1992) Physiological Effects of Brief Air Exposure in Exhaustively Exercised Rainbow Trout (*Oncorhynus mykiss*): Implications for "Catch and Release" Fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, 49, 1157–1162.

A replicated study in 2000–2001 of bottom fishing grounds in the Bay of Biscay, Spain (1) found that reducing air exposure under commercial fishing conditions did not increase the survival of unwanted small-spotted catshark *Scyliorhinus canicular*, but it was increased under research fishing conditions. Catshark survival rates were similar between exposure times (sorting time on deck) on commercial trawling trips (20 min: 82%, 30 min: 80%, 40 min: 78%, 60 min: 68%, 85 min: 64%). However, survival rates were improved with shorter times on deck during bottom trawl survey deployments (20 min: 100%, 30 min: 94%, 40 min: 92%, 60 min: 81%). The authors noted that although a weak effect was found under commercial conditions, survival did not appear to be affected by sorting time or tow duration (data reported as graphical analysis). Data were collected from otter trawl deployments during commercial fishing trips (16 hauls) and bottom trawl surveys (20 hauls). For each deployment, groups of twenty catshark were exposed to air: for six intervals between 18–85 min during commercial deployments and 20, 30, 40 and 60 min intervals during the trawl survey. Tow duration was 180–360 minutes for commercial deployments and 30 minutes during the survey. After each period of time on deck after capture, catshark were transferred to onboard tanks and survival was assessed after 1 h.

A replicated study in 2015–2016 in two areas of pelagic water in the Gulf of Alaska off British Columbia, Canada (2) found that shorter durations of air exposure reduced levels of injury and improved physical condition of unwanted chum salmon *Onchorynchus keta* caught in purse seine nets. In both areas, salmon injury was lower and physical condition was better for shorter durations of air exposure during handling than longer (data reported as statistical model results). In addition, shorter holding times in the purse seine before retrieval were associated with improved physical condition (data reported as statistical model results). Experimental purse seining was carried out on two fishing trips targeting Pacific salmon *Onchorynchus* spp., in July-August 2015 and 2016. The effects of air exposure (1–12 min) and experimental holding times (4–43 min) on discarded chum salmon were investigated. Injury was scored based on scale loss, skin loss, wound depth and fin damage. Fish physical condition was scored according to the number of reflexes (e.g. burst swimming, orientation, eye movement, fight response and ventilation) that were impaired.

A study in 2014 in an area of coral reef on the Great Barrier Reef, Coral Sea, Australia (3) found that the overall behaviour of reef fish released after minimal air exposure was improved compared to longer air exposure. Average time spent immobile under the boat following release was lower after "low stress" handling with no air exposure than "high stress" handling that included air exposure for coral trout *Plectropomus leopardus* (low: 4 s, high: 9 s), emperor fish *Lethrinus* spp. (low: 0 s, high: 1 s) and Spanish flag snapper *Lutjanus carponotatus* (low: 0 s, high: 9 s). Time to reach the nearest reef was also lower (trout, low: 13 s, high: 19 s; emperor, low: 10 s, high: 19 s; snapper, low: 18 s, high: 33 s). Time taken to enter shelter was not affected by handling conditions, but varied with species (trout, low: 20 s, high: 24 s; emperor, low: 20 s, high: 135 s; snapper, low: 108 s, high: 130 s). In addition, fish subject to lower air exposure (all species) took less time to reach the ocean floor and exhibited higher tailbeat and ventilation rates (see original paper for data). In August-September 2014, a total of 62 fish were caught by hook and line from reefs 5–20 m deep and transferred to a 30,000 l tank. After 1–5 days, fish were transported by boat to a release site 8–12 m from the nearest reef. Fish were released after "low stress" handling (no forced exercise or air exposure) or "high stress" handling (1 min forced exercise, 5 min air exposure) to simulate capture by hook and line.

(1) Rodríguez-Cabello C., Fernández A., Olaso I. & Sánchez F. (2005) Survival of small-spotted catshark (*Scyliorhinus canicula*) discarded by trawlers in the Cantabrian Sea. *Journal of the Marine Biological Association of the United Kingdom*, 85, 1145–1150.

(2) Cook K.V., Hinch S.G., Watson M.S., Patterson D.A., Reid A.J. & Cooke S.J. (2018) Experimental capture and handling of chum salmon reveal thresholds in injury, impairment, and physiology: Best practices to improve bycatch survival in a purse seine fishery. *Fisheries Research*, 206, 96–108.

(3) Raby G.D., Messmer V., Tobin A.J., Hoey A.S., Jutfelt F., Sundin, J., Cooke S.J. & Clark T.D. (2018) Swim for it: effects of simulated fisheries capture on the post-release behaviour of four Great Barrier Reef fishes. *Fisheries Research*, 206, 129–137.

2.27 Release protected or species of concern alive after capture

- **Six studies** examined the effects of releasing protected or species of concern alive after capture on marine fish populations. Two studies were in the Atlantic Ocean[2,4] (USA and Canada), and one was in each of the Coral Sea[3] (Australia), Tasman Sea[6] (New Zealand), Cantabrian Sea[1] (Spain) and the Pacific Ocean[5] (USA).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (6 STUDIES)

- **Survival (6 studies):** Four of six replicated studies in the Atlantic Ocean[2,4], Tasman Sea[3,6], Cantabrian Sea[1] and the Pacific Ocean[5] found that the majority (76–92%) of unwanted (discarded or protected) small-spotted catshark[1], thorny skate[2], pearl perch[3] and Atlantic wolffish[4], but less than half of smooth skate[2], survived for at least 1 h–5 days after capture and/or release, and survival was reduced by hooking/capture depth injuries[3] and longer tow durations[4]. One study[5] found that nearly all yelloweye rockfish survived for four days after capture and release, but canary rockfish survival decreased with increasing capture depth. The other study[6] found that all spinetail devilrays brailed aboard from purse seine nets survived but not those brought aboard entangled in the net.

BEHAVIOUR (0 STUDIES)

Background

Releasing protected or other threatened fish species alive after incidental capture should, in theory, protect the released individuals and wider populations, particularly weaker ones, from fishing mortality and overexploitation. However, the effectiveness of live release relies on a range of factors affecting the survival of fish post-capture, including: the extent of damage from the gear, fishing duration, catch size, exposure to the air and temperature changes, depth of capture and behavioural impairments that increase the chance of predation after release (Davis 2002). In some countries where commercial fish catches are managed by quota limits, there are policies that state fish cannot be returned to the sea unless certain conditions are met, such as evidence of the species having a high likelihood of survival (Ellis *et al.* 2016). Survival may depend on multiple factors including species vulnerability, capture method (and depth of capture), duration of time exposed to the air and handling techniques.

For related interventions, see *'Handling of catch'*.

Davis M.W. (2002) Key principles for understanding fish bycatch discard mortality. *Canadian Journal of Fisheries & Aquatic Sciences*, 59, 1834–1843.

Ellis J.R., McCully Phillips S.R. & Poisson, F. (2016) A review of capture and post-release mortality of elasmobranchs. *Journal of Fish Biology,* 90, 653–722.

A replicated study in 2000–2001 of bottom fishing grounds in the Cantabrian Sea, Spain (1) reported that a large proportion of unwanted (discarded) small-spotted catshark *Scyliorhinus canicula* survived after capture by commercial trawl nets. In commercial trawl catches, average catshark survival was 78% (range 47–91%). In addition, increases in sorting time during sorting of catches had a weak effect on survival (i.e. slightly decreased it), however there was no influence of haul duration (3–6 h; data reported as graphical analysis). In all but one haul there was no difference in survival between male and female catsharks (data reported as statistical results). Data were collected from otter trawl deployments during commercial fishing trips (16 hauls). For each deployment, groups of twenty catshark (10 of each sex) were selected and were exposed to air for roughly six different intervals between 18–85 min. After each interval, catshark were transferred to onboard tanks and survival was assessed after 1 h.

A replicated study in 2009–2011 on an area of sandy and muddy seabed in the Gulf of Maine, north Atlantic Ocean, USA (2) reported that a large proportion of unwanted (prohibited) thorny skate *Amblyraja radiata*, but less than half of unwanted smooth skate *Malacoraja senta,* survived for three days after incidental capture in otter trawls targeting little skate *Leucoraja erinacea* and winter skate *Leucoraja ocellata*. Across all tow durations, overall survival of unwanted thorny and smooth skates after 72 h was 81% and 41% respectively. For the two commercial skates, overall survival was 92% (winter) and 86% (little). In addition, for all skates combined, species was the only significant factor affecting survival (out of other factors include catch biomass, temperature, tow duration). Individually, there were no significant predictors of 72 h mortality detected for thorny skate (data reported as statistical results; insufficient data for smooth skate). Data were collected from skates caught in 71 otter trawl deployments. Immediate mortality of skates was assessed before randomly selected live skates were transferred to deck tanks, then to sea pens that were lowered to the seafloor. Sea pens were retrieved after 72 h to assess mortality and all live skates released.

A replicated study (year not stated) of two areas of rocky reef and gravel in the Coral Sea off Australia (3) found that the majority of pearl perch *Glaucosoma scapulare* released alive after capture by hook and line survived for up to three days, and survival was influenced by hook location and signs of barotrauma (effects of capture at depth). The overall short-term (3 day) post-release survival rate of perch was 92%. In addition, survival rates were higher for perch hooked in the lip or mouth (93–100%) than those hooked in the throat (36%), and for those with no obvious signs of barotrauma (93%) compared to fish observed with swollen or everted stomachs (63–69%). Data were collected for 183 pearl perch (19–61 cm total length) caught during four field trips (dates/year of sampling unspecified) using conventional baited rod and reel, in one shallow (<80 m) and one deep (>80 m) area off the coast of Queensland, 50 nm apart. Hook location was recorded before the captured perch were tagged and placed either into onboard holding tanks or vertical enclosures anchored to the seabed. Post-release survival was assessed after three days.

A replicated study in 2004 in bottom fishing grounds in the Atlantic Ocean off Canada (4) found that Atlantic wolffish *Anarhichas lupus* (protected species) caught in the yellowtail flounder *Limanda ferruginea* trawl fishery typically survived for five days after capture and release. Overall post-capture survival of 41 wolffish (either kept in holding tanks for 48 h or held in tanks for 10 h before being placed in sea cages on the seabed for 2 d) ranged from 0–100%. However, survival varied with duration of air exposure after capture, with most individuals exposed to air for periods <2 h surviving (<30 min: 100%, 30 min–1 h: 88%, 1 h–1.5 h: 100%, 1.5–2 h: 90%), while none of the 4 fish exposed for >2 h survived. In autumn 2004, post-capture survival of wolffish captured in yellowtail flounder trawl net deployments was assessed. A total of 23 wolffish were held in temporary holding tanks and survival assesses up to 48 h, and 18 wolffish were held in tanks for 10 h before being moved to holding cages deployed on the seafloor where survival was monitored for up to 2 d.

A replicated study in 2012–2013 in two areas of pelagic water in the Pacific Ocean, off Oregon, USA (5) found that almost all protected yelloweye rockfish *Sebastes ruberrimus* survived for four days after capture and release, but post-release survival of protected canary rockfish *Sebastes pinniger* decreased with capture depth. Overall post-release survival of yelloweye rockfish *Sebastes ruberrimus* was 95% (77 of 81 fish survived), while survival of canary rockfish *Sebastes pinniger* was 78% (42 of 54 fish survived). Estimates (to compensate for small sample sizes) of the proportion of yelloweye rockfish surviving with capture depth were similar (83–93%) across all five depth ranges sampled. For canary rockfish, estimated survival decreased with increasing depth of capture; >75% at depths of 46–84 m, decreasing to 25% at depths below 135 m. In coastal waters of the USA, non-retention rules for several species of Pacific rockfishes formed part of the Pacific Coast Fishery Management Plan of 2012. Sampling was done between September 2012 and October 2013 at two areas near Stonewall Bank, off Newport. A total of 81 yelloweye and 54 canary rockfish were caught with rod and reel from five depth zones across a total depth range of 46–175 m. After capture, each fish was placed in a specifically designed cage that was then deployed in the sea at a depth similar to the depth at fish capture. Cages were retrieved after 44–96 h and survival recorded.

A replicated study in 2013–2015 in coastal pelagic waters of the Tasman Sea, off northern New Zealand (6) found that some individuals of the protected and endangered spinetail devilray *Mobula japonica* survived release after accidental capture in purse-seine nets and normal handling practices, but survival was decreased in rays brought aboard entangled in the net. Three of seven data tagged devilrays survived capture and release, two over monitoring lengths of 30 days and one with a monitoring length of 82 days. Four rays died within 1–2 days of release, indicated by rapid descents in the data to ~1,800 m. All three rays that survived had been brought onboard from the purse-seine in a convey net, or brailer, and released directly from the convey net or using a rope and winch. All rays that died had been entangled in a part of the net (bunt) and hauled onboard in the final section of the main purse-seine net. Rays were tagged by observers aboard commercial skipjack purse-seine vessels after being lifted on deck. Only rays hauled onboard were tagged as those released whilst in the water were all expected to survive. Satellite-archival tags were anchored in the central part of the wing musculature using an umbrella anchor with eight plastic barbs. Anchors were attached to tags by 10-11 cm monofilament nylon or stainless-steel tethers. Tags were secondarily attached to the wing with a numbered conventional plastic tag and had a release device that triggered at 1,700–1,800 m.

(1) Rodríguez-Cabello C., Fernández A., Olaso I. & Sánchez F. (2005) Survival of small-spotted catshark (*Scyliorhinus canicula*) discarded by trawlers in the Cantabrian Sea. *Journal of the Marine Biological Association of the United Kingdom*, 85, 1145–1150.

(2) Mandelman J.W., Cicia A.M., Ingram Jr G.W., Driggers III W.B., Coutre K.M. & Sulikowski J.A. (2013) Short-term post-release mortality of skates (family Rajidae) discarded in a western North Atlantic commercial otter trawl fishery. *Fisheries Research*, 139, 76–84.

(3) Campbell M.J., McLennan M.F. & Sumpton (2014) Short-term survival of discarded pearl perch (*Glaucosoma scapulare* Ramsay, 1881) caught by hook-and-line in Queensland, Australia. *Fisheries Research*, 151, 206–212.

(4) Grant S.M. & Hiscock W. (2014) Post-capture survival of Atlantic wolffish (*Anarhichas lupus*) captured by bottom otter trawl: Can live release programs contribute to the recovery of species at risk? *Fisheries Research*, 151, 169–176.

(5) Hannah R.W., Rankin P.S. & Blume M.T.O. (2014) The divergent effect of capture depth and associated barotrauma on post-recompression survival of canary (*Sebastes pinniger*) and yelloweye rockfish (*S. ruberrimus*). *Fisheries Research*, 157, 106–112.

(6) Francis, M.P. & Jones E.G. (2017) Movement, depth distribution and survival of spinetail devilrays (*Mobula japanica*) tagged and released from purse-seine catches in New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 27, 219–236.

2.28 Establish handling and release protocols in non-recreational fisheries

- **Two studies** examined the effects of establishing handling and release protocols in non-recreational fisheries on marine fish populations. One study was in the Atlantic Ocean[1] (West Africa) and one was in the South Pacific Ocean[2] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One study in the Atlantic Ocean[1] reported that tracked whale sharks released from purse seines using an enhanced protocol survived for at least 21 days, and post-release movements appeared normal.

BEHAVIOUR (2 STUDIES)

- **Behaviour change (2 studies):** One study in the Pacific Ocean[2] found that after release protocols (minimal handling and air exposure), reef fish returned more quickly to a reef or the seabed after release, compared to higher stress handling and longer air exposure. One study in the Atlantic Ocean[1] reported that the post-release movements of tracked whale sharks released from purse seines using an enhanced protocol appeared normal.

Background

Releasing alive unwanted animals from fishing catches back into the sea helps reduce the ecosystem impacts of fisheries (Raby *et al.* 2018). There is a presumption that a released animal is likely to behave normally and survive, but some captured fish show signs of lethargy before release (Davis 2000). Lethargic fish are at risk of reduced survival and may be more prone to predation by other marine animals and seabirds upon release (Broadhurst 1998). Adopting handling and release protocols which may improve vitality of returned fish would reduce the likelihood of their post-release predation. Efficient handling and release methods may also reduce fish injuries and any impacts of exposure of fish to the air. The minimising of both of these factors may help improve survival.

For related interventions, see *'Handling of catch'*.

Broadhurst M.K. (1998) Bottlenose dolphins, *Tursiops truncatus*, removing by-catch from prawn-trawl codends during fishing in New South Wales, Australia. *Marine Fisheries Review*, 60, 9–14.

Davis M.W. (2010) Fish stress and mortality can be predicted using reflex impairment. *Fish and Fisheries,* 11, 1–11.

Raby G.D., Messmer V., Tobin A.J., Hoey A.S., Jutfelt F., Sundin, J., Cooke S.J. & Clark T.D. (2018) Swim for it: effects of simulated fisheries capture on the post-release behaviour of four Great Barrier Reef fishes. *Fisheries Research*, 206, 129–137.

A study in 2014 in pelagic waters of the eastern Atlantic Ocean off the African continent (1) reported that tracked whale sharks *Rhincodon typus* released using an enhanced protocol from purse-seine nets targeting tuna *Thunnus* spp. survived for at least 21 days and movements showed no unusual behaviour. Of six satellite-tagged whale sharks, data were transmitted only from five (the fate of the other was unknown) for a period of at least 21 days following shark release. Three tags detached at the programmed 30 days after release, and two at 21 and 71 days (programmed to 30 and 90 days respectively). The detachment after 21 days was due to a deep dive, and the cause of the detachment after 71 days was unknown, although all sharks were assumed to have survived post-release from the purse-seine nets. Movement patterns, including vertical dives, were considered within normal behaviour (data presented graphically). Six whale sharks were tagged after capture in tuna purse-seine nets in the eastern Atlantic in 2014. Sharks were released using an improved version of a previously proposed method involving a cable being first fed through the net, then attached to the opposite edge of the net near the whale shark's head. The net is then slackened, and the cable tightened to position it underneath the whale shark's head, which rolls over the float line of the net as the cable is tightened. The float line then sinks with the weight of the shark, which rolls out of the net as the cable is alternately tightened and slackened. Full details of the handling methods are provided in the original study.

A study in 2014 in an area of coral reef on the Great Barrier Reef, South Pacific Ocean, Australia (2) found that the ability of fish to return to the reef or seabed after handling and release was affected by handling technique and air exposure. Average time spent immobile following release was higher after "high stress" handling (1 min forced exercise, 5 min air exposure) than "low stress" handling (no forced exercise or air exposure) for coral trout *Plectropomus leopardus* (4 vs 9 s), emperor *Lethrinus* spp. (0 vs 1 s) and snapper *Lutjanus carponotatus* (0 vs 9 s). Time to reach the nearest reef was also higher after high stress handling than low stress handling (trout: 13 vs 19, emperor: 10 vs 19, snapper: 18 vs 33 s), although the time taken to find shelter was similar (coral trout: 20 vs 24, emperor: 20 vs 135, snapper: 108 vs 130 s). In addition, fish subject to high stress handling (all species) took longer to reach the ocean floor and exhibited lower tailbeat and ventilation rates. The proportion of time immobile was similar between treatments for all species except snapper, which spent more time immobile after high stress handling. Sixty-two fish caught by hook and line from reefs at depths of 5–20 m were transferred to a 30,000 l tank where they were fed every 2–3 days. After 1–5 days, fish were transported by boat to a release site 8–12 m from the nearest reef. Fish were released after high or low stress handling to simulate angling practice.

(1) Escalle L., Murua H., Amande J.M., Arregui I., Chavance P., Delgado de Molina A., Gaertner D., Fraile I., Filmalter J.D. Santiago J., Forget F., Arrizabalaga H. Dagorn L. & Merigot B. (2016) Post-capture survival of whale sharks encircled in tuna purse-seine nets: tagging and safe release methods. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26, 782–789.

(2) Raby G.D., Messmer V., Tobin A.J., Hoey A.S., Jutfelt F., Sundin, J., Cooke S.J. & Clark T.D. (2018) Swim for it: effects of simulated fisheries capture on the post-release behaviour of four Great Barrier Reef fishes. *Fisheries Research*, 206, 129–137.

Quotas

2.29 Set quotas for non-targeted commercial catch

- **One study** examined the effects of setting quotas for non-targeted commercial fish species on marine fish populations. The study was in the Pacific Ocean[1] (Canada).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Reduction of unwanted catch (1 study):** One before-and-after study in the Pacific Ocean[1] found that implementing a quota limit for non-target commercial catch reduced the amount of unwanted halibut, but a previous quota system based on the whole catch (individual transferrable quotas) did not.

Background

Fishing quotas set a maximum limit on the seasonal or annual quantity of fish that can be caught by a vessel in a given area or fishery and may apply to one or more species. One such type of quota (termed individual transferable quota or ITQ) is used to restrict the overall amount of fish a fishing fleet can catch. As the name suggests, transferable quotas can be bought, sold or leased between vessels. However, another type of quota (termed individual vessel bycatch quota or ITBQ) can be implemented. Unlike ITQs, ITBQs are not transferable and put a limit on the unwanted/discarded proportion of fish a vessel can catch that isn't retained for market (fish may not be kept for market for a variety of reasons, including the species being of no value and/or target species that are undersized or exceed the quota). They aim to reduce unwanted catches of fish by not only limiting overall fishing mortality, but by also encouraging active avoidance of unwanted catch by fishers that may have to stop fishing once their non-target quota is reached (O'Keefe *et al.* 2014).

O'Keefe C.E., Cadrin S.X. & Stokesbury D.E. (2014) Evaluating effectiveness of time/area closures, quotas/caps, and fleet communications to reduce fisheries bycatch. *ICES Journal of Marine Science,* 71, 1286–1297.

A before-and-after study in 1962–2006 of bottom fishing grounds in the northwest Pacific Ocean off British Columbia, Canada (1) found that in the 10 years after implementing an individual vessel quota system for unwanted catch ("bycatch") in a multispecies groundfish fishery, the unwanted catch of Pacific halibut *Hippoglossus stenolepis* (a prohibited species) was reduced, but a previous quota system limiting the amount of the whole catch (individual transferrable quotas) increased halibut catch. In the period 1996–2006 following the introduction of a "bycatch" quota system for individual vessels in 1996, halibut catches fell by 219% (data reported as statistical model results). Conversely, when individual transferrable catch quotas had been implemented in 1990, it resulted in a 40% increase in unwanted halibut catches (data reported as statistical model results). Authors noted that this increase was due to individual transferrable quotas tending to only consider the conservation of a single species rather than multiple species caught at the same time. Fisheries data from the British Columbia groundfish fishery for the period 1962–2006 were analysed, provided by The International Pacific Halibut Commission and Fisheries and Oceans Canada. The British Columbia Groundfish fishery implemented an individual vessel bycatch quota system in 1996 whereby trawl license holders received a quota representing a percentage of the species-specific total allowable catch.

(1) Edinger T. & Baek J. (2015) The role of property rights in bycatch reduction: Evidence from the British Columbia Groundfish fishery. *Fisheries Research*, 168, 100–104.

2.30 Legislate to oblige fishers to retain and land all catch of species managed by quotas

- We found no studies that evaluated the effects of legislating to oblige fishers to retain and land all catch of quota species on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

In commercial fisheries, fish are returned back into the sea after capture, or discarded, for a number of reasons including fish being too small, of no/low value, or because the fisher has already met their maximum allowed catch (quota) for a species. Discarding is widely considered a wasteful practice if the fish is dead upon capture or is likely to die once returned (Condie *et al.* 2014). Legislation has recently come into force in European fisheries, obliging fishers to retain all (e.g. all sizes etc) catches of commercially-caught quota species (although a few exemptions exist, such as if there is clear evidence a species is likely to survive post-release). Historically, discarding of rockfish in the British Columbia groundfish trawl fishery has been prohibited, as well as a full discard ban in the Faroe Island fisheries (Condie *et al.* 2014) and a discard ban for Pacific cod and pollock in the US Alaskan groundfish fisheries. The aim is that banning discarding will incentivise fishers to operate more selectively, using gear which help avoid capture of small or unwanted fish in the first place.

Condie H.M., Grant A. & Catchpole T.L. (2014) Incentivising selective fishing under a policy to ban discards; lessons from European and global fisheries. *Marine Policy,* 45, 287–292.

Fishing gear modification

2.31 Use artificial light on fishing gear

- **Two studies** examined the effects of using artificial light on fishing gear on marine fish populations. One study was in the Pacific Ocean[1] (USA) and one in the Barents Sea[2] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (1 study):** One replicated, paired, controlled study in the Pacific Ocean[1] found that shrimp trawl nets with artificial lights caught fewer unwanted fish when they were fitted to the fishing line, but not to a size-sorting grid, compared to a conventional trawl.
- **Improved size-selectivity of fishing gear (1 study):** One replicated, controlled study in the Barents Sea[2] found that size-selectivity of long rough dab, Atlantic cod, haddock and redfish was not improved by the presence of LED lights on a size-sorting grid.

Background

Many fishing gears incidentally capture unwanted non-commercially targeted species or sizes. Different species show different behavioural responses to light (Ryer & Olla 2000; Ryer & Barnett 2006; Walsh & Hickey 1993). Some may be attracted to the presence of lights, however, some may avoid them or they may enable some fish to see the fishing gear and move away from it. Fitting artificial lights (e.g. LEDs) to fishing gear during deployment may reduce the amount of unwanted species that interact with and are retained by fishing gear.

For a similar intervention relating to using fish deterrents on fishing gear, see *'Fishing gear modification - Attach an electropositive deterrent to fishing gear'*.

Ryer C.H. & Olla B.L. (2000) Avoidance of an approaching net by juvenile walleye pollock *Theragra chalcogramma* in the laboratory: the influence of light intensity. *Fisheries Research*, 45, 195–199.

Ryer C.H. & Barnett L.A. (2006) Influence of illumination and temperature upon flatfish reactivity and herding behavior: potential implications for trawl capture efficiency. *Fisheries Research*, 81, 242–250.

Walsh S.J. & Hickey W.M. (1993) Behavioural reactions of demersal fish to bottom trawls at various light conditions. *ICES Marine Science Symposium*, 196, 68–76.

A replicated, paired, controlled study in 2014 in an area of seabed in the Pacific Ocean, off Oregon, USA (1) found that a shrimp trawl net with artificial lighting attached caught less unwanted fish catch in one of two configurations, compared to trawl nets without artificial lighting. In trials with artificial lights attached along the fishing line, fewer of five of five fish species/groups were caught than trawls without lights: Pacific eulachon *Thaleichthys pacificus* (1 vs 11 kg/haul), slender sole *Lyopsetta exilis* (1 vs 2 kg/haul), darkblotched rockfish *Sebastes crameri* (95 vs 537 kg/haul), other juvenile rockfish *Sebastes* spp. (55 vs 126 kg/haul) and other small flatfish *Pleuronectiformes* (171 vs 559 kg/haul). In trials with artificial lights located near to a size sorting grid, catch rates were similar for three of the five species/groups compared to trawls without lights: darkblotched rockfish (390 vs 428 kg/haul), juvenile rockfish (72 vs 109 kg/haul) and small flatfish (291 vs 287 kg/haul); and were higher for eulachon (33 vs 16 kg/haul) and sole (1.5 vs 0.8 kg/haul). Catches of target ocean shrimp *Pandalus jordani* were similar (or the same) with and without lights, irrespective of location (fishing line, with: 204, without: 205 kg/haul; grid, with and without: 117 kg/haul). In July 2014, paired shrimp trawls were fitted with standard trawls with a rigid size-sorting grid (19 mm bar spacing). Trawls with 10 green lights fitted to the fishing line (42 trawls) or one to four lights fitted next to the grid (12 trawls) were compared with trawls without lights. Catches from each net were sorted by species, counted and weighed.

A replicated, controlled study in 2016 in an area of seabed in the Barents Sea, Norway (2) found that shrimp trawls with LED lights attached to a size-sorting escape grid did not improve the size-selectivity of long rough dab *Hippoglossoides platessoides*, Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus* and redfish *Sebastes* spp. to trawls without lights on the grid. The probability of capture across all sizes was similar with and without LED lights for all four species (data reported as graphical analysis). For each species, the length at which fish had a 50% chance of escape was similar with and without lights: plaice (19 vs 19 cm), cod (19 vs 19 cm), haddock (17 vs 15 cm) and redfish (14 vs 14 cm). Catch probabilities of commercial target deep-water shrimp *Pandalus borealis* were also similar between trawl designs (data reported as graphical analysis). In November 2016, a total of 16 experimental deep-water shrimp deployments were carried out in darkness at 361–383 m depths. Trawl nets were fitted with a rigid Nordmøre size-sorting escape grid (1.5 × 0.75 m) with a mesh guiding panel to direct catch to the bottom of the grid and a triangular escape outlet in the upper trawl panel. Eight of the 16 trawls were fitted with four green LEDs positioned on the lower section of the grid pointing in the towing direction at the same angle as the grid, and eight were without LEDs. A 19 mm mesh cover sampled fish escaping through the escape outlet.

(1) Hannah R.W., Lomeli M.J.M. & Jones S.A. (2015) Tests of artificial light for bycatch reduction in an ocean shrimp (*Pandalus jordani*) trawl: Strong but opposite effects at the footrope and near the bycatch reduction device. *Fisheries Research*, 170, 60–67.
(2) Larsen R.B., Herrmann B., Sistiaga M., Brčić J., Brinkhof J. & Tatone I. (2018) Could green artificial light reduce bycatch during Barents Sea Deep-water shrimp trawling? *Fisheries Research*, 204, 441–447.

2.32 Attach an electropositive deterrent to fishing gear

- **Nine studies** examined the effect of attaching an electropositive deterrent to fishing gear on marine fish populations. Three studies were in the Atlantic Ocean[3,4,7] (USA, Canada, Bahamas). One study was in each of the Gulf of Alaska[1] (USA), the South Pacific Ocean[8] (Australia) and the Tasman Sea[9] (Australia). One study was a global systematic review[6] and two studies were in laboratory facilities[2,5] (USA).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (4 STUDIES)

- **Behaviour change (4 studies):** Three of four replicated studies (one paired and controlled, one randomized and controlled, one randomized, and one controlled) in the Atlantic Ocean[7], Tasman Sea[9], and in laboratory conditions[2,5], found that the presence of potentially deterrent materials attached near the bait reduced the frequency of feeding attempts and bait consumption of spiny dogfish[2], great hammerhead[7] and draughtboard sharks[9] compared to the absence of deterrent materials. The other study[5] found that a potentially deterrent material did not reduce bait consumption by bonnethead and young lemon sharks compared to non-deterrents. One of the studies[2] also found that the bait consumption behaviour of commercially valuable Pacific halibut was unaffected by deterrent materials.

OTHER (5 STUDIES)

- **Reduction of unwanted catch (5 studies):** Two of four replicated, controlled studies (one randomized) in the Gulf of Alaska[1], the Pacific Ocean[8] and the Atlantic Ocean[3,4] found that fishing gear (longlines and traps) fitted with electropositive deterrent materials caught fewer unwanted spiny dogfish[1], longnose skate[1], sharks and rays[8], and fewer undersized halibut[1], compared to standard fishing gear or gears with non-deterrent materials. The other two studies[3,4], and a global systematic review[6] found that electropositive deterrents on fishing gear resulted in similar catches of unwanted spiny dogfish[3], sharks[4] (total catch), blue shark[4] and sharks and rays[6] (total catch), compared to gear with no deterrents.

Background

Many fishing gears, as well as catching target commercial species, catch unwanted species. These may be species for which a quota has been reached, those of conservation concern or species that hold no commercial value. Fishing gears may be fitted with devices or substances that exploit a species' natural reaction to sensory stimulation to deter them from interacting with fishing gear and reduce incidental catch. Elasmobranchs (sharks, skates and rays), for example, have specialized electroreceptors that aid in the detection of prey, predators and potential mates (Rivera-Vicente *et al.* 2011), and fitting electropositive metals and/or permanent magnets (i.e. substances that generate an electrical or magnetic field) to fishing gear may elicit avoidance behaviour to gears or baits in such species.

Evidence for similar deterrent devices on fishing gear is summarized under *'Fishing gear modification - Use artificial light on fishing gear'*.

Rivera-Vicente A.C., Sewell J. & Tricas T.C. (2011) Electrosensitive spatial vectors in elasmobranch fishes: implications for source localization. *PLoS One*, 6, e16008.

A replicated, randomized, controlled study in 2007 of an area of fished seabed in in the Gulf of Alaska, USA (1) found that longline hooks with electropositive metal attached reduced the catches of unwanted spiny dogfish *Squalus acanthias*, longnose skate *Raja rhina* and undersized commercially targeted Pacific halibut *Hippoglossus stenolepis*, compared to standard hooks, and in most cases compared to hooks with non-electropositive metal attached. Catch rates were lower on electropositive hooks than standard and steel-fitted hooks for spiny dogfish (positive: 17, standard: 21, steel: 19 ind./50 hooks) and longnose skate (positive: 13, standard: 24, steel: 23 ind./50 hooks). Undersized (<82 cm) halibut catch rates were lower on electropositive hooks (1 ind./50 hooks) than standard hooks (2 ind./50 hooks) but similar to steel-equipped hooks (1 ind./50 hooks). Overall catch rates of halibut (all sizes) were similar between all hook types (3 ind./50 hooks). In September and October 2007, thirty-six longline sets were deployed in Kachemak Bay at 16–58 m depths of three hook types: circle hooks equipped with electropositive cerium mischmetal (a nonmagnetic metal alloy), standard circle hooks, and circle hooks equipped with inert steel that mimicked the mischmetal. All hooks were baited with 110–150 g of chum salmon *Oncorhynchus keta*. Hooks were fixed to a groundline in randomized blocks of 150 for each type (450 hooks/set) using 31 cm nylon lines attached to the groundline every 5.5 m. Gear was hauled after a minimum soak time of 90 min (average 192 min).

A replicated, paired, controlled study in 2006 in a laboratory in the USA (2) found that the bait attacking behaviour of spiny dogfish *Squalus acanthias* (an unwanted catch species), but not commercially valuable Pacific halibut *Hippoglossus stenolepis,* was reduced in the presence of one of two potentially deterrent materials (mischmetal but not magnets), compared to inert metals. Overall, in the presence of mishmetal, both the times taken for dogfish to first bite the bait (mischmetal: 2–19 min, inert: 1–2 min) and the times taken to remove the bait (mischmetal: 4–30 min, inert: 2–4 min) were higher compared to the inert metals, irrespective of the period of food deprivation. Using magnets as the deterrent, overall bait attack and removal times by dogfish were not significantly different compared to the inert metals (magnet: 1–5 min, inert: 1–2 min). However, dogfish showed strong behavioural avoidance responses (flinch, disorientation) to both the deterrent materials, but not to the inert metals. For halibut, there were no responses to the either the deterrent materials or the inert metals, and bait removal times were similar (deterrents: <1–30 min, inert: <1–30 min). In 2006, two types of potential deterrents (non-magnetic mischmetal alloy and magnets) and an inert stainless steel/aluminium material were tested separately on 12 dogfish and 16 halibut held in indoor pools. Each material was suspended on a short section of twine above pieces of squid *Loligo opalescens* bait (no hooks). Deterrent/baits were presented simultaneously in pairs with the inert/bait material and behavioural responses recorded by video. Trials were done on dogfish (5 trials) and halibut (4 trials) deprived of food for periods of up to 4 d (16–20 trials/species/food deprivation period).

A replicated, controlled study in 2007 in an area of pelagic water in the Gulf of Maine, USA (3) found that attaching mischmetal (a nonmagnetic metal alloy) to commercial and recreational hook fishing gears did not reduce catches of spiny dogfish *Squalus acanthias* compared to hooks with no mischmetal. Total numbers of dogfish caught with mischmetal present was not statistically different from when mischmetal was absent for commercial longlines (present: 221 fish; absent: 244 fish) or rod and reel (jig) gear (present: 14 fish; absent: 16 fish). Fishing took place in August/September 2007 over 10 days. Pieces of mischmetal (45 × 45 mm and 5 mm thick) were attached 10 cm above the hook and bait on longlines and jigging gears. A total of 21 longlines (2,080 hooks, half with mischmetal and half without) were set for 1–2 h. Jigging using rod and reel took place during the longline deployments. Three rod and reels were configured with two hooks, one with mischmetal attached and one without. Seventy-three jig lines were set (146 baited hooks, half with mischmetal, half without). Captured fish were recorded by hook and bait type.

A replicated, controlled study in 2011 in an area of pelagic water in the northwest Atlantic Ocean off Nova Scotia, Canada (4) found that longline hooks with electropositive metal attached did not reduce the unwanted catches of sharks (*Selachii*) overall or of blue shark *Prionace glauca* compared to standard hooks. Total shark catches (all species) were not statistically different between hooks with electropositive weights (33 ind./1,000 hooks), standard hooks (36 ind./1,000 hooks), or hooks with inert lead weights (44 ind./1,000 hooks). Blue shark catches were also similar across hook types (electropositive: 31, standard: 33, inert: 40 ind./1,000 hooks). Catches of other unwanted sharks (mako *Isurus oxyrinchus*, porbeagle *Lamna nasus*) and other, commercially valuable species (bluefin tuna *Thunnus thynnus*, albacore *Thunnus alalunga,* anglerfish *Lophiiformes* spp.) were generally low across all hook types (data not tested statistically). Target catches of swordfish *Xiphias gladius* were lower on hooks with electropositive weights (12 fish/1,000 hooks) and lead weighted hooks (10 fish/1,000 hooks) compared to standard hooks (23 fish/1,000 hooks). In September and October 2011, a total of 6,300 hooks were set during 70 experimental gear sets (900 hooks/set) in a longline swordfish *Xiphias gladius* fishery. Each set used three hook types: standard hooks, hooks with electropositive metal weights (neodymium and praseodymium), and hooks with inert lead weights, with 300 hooks/hook type.

A replicated, randomized study in 2010–2011 in a laboratory in Florida, USA (5) found that a potentially deterrent metal (neodymium) attached to bait did not reduce the incidence of bait capture by bonnethead shark *Sphyrna tiburuo* or young lemon shark *Negaprion brevirostris*, compared to three non-deterrent materials. Across trials, the percentages of bites taken to remove bait from the neodymium was similar to all three other materials for both bonnetheads (neodymium: 27–32%, acrylic: 23–25%, lead: 22–23%, and stainless steel: 23–27%) and young lemon sharks (neodymium: 35%, acrylic: 23%, lead: 23%, and stainless steel: 21%). A total of 12 bonnethead sharks and 13 immature lemon sharks caught by gillnet and hook and line fishing in September 2010–August 2011, were maintained in an aquarium. After one week to acclimatise, sharks were starved for 48 h. Four equal-sized (2.5 × 2.5 × 0.6 cm) pieces of neodymium (the test material), acrylic, lead, and stainless steel were put in a shallow (0.9 m depth × 4.6 m diameter) tank fixed to a 1m^2 acrylic plate. Position of each material was randomized each trial. Sharks were introduced to the tank and the baited (shrimp for bonnethead, mullet and herring for lemon sharks) plates they bit were recorded. Bonnethead sharks were tested individually and in groups of 2–4 and lemon sharks were tested only in groups of 2–4 (see original paper for full methods).

A systematic review in 2015 of 17 relevant studies of 44 in global pelagic waters (6) of devices to reduce unwanted catch, found that using electropositive and magnetic materials, or a combination of both, on hooks in longline fisheries did not reduce the amount of unwanted sharks and rays (*Elasmobranchii*) caught overall, compared to traditional J hooks alone. Data were reported as percentage catch reductions relative to the standard. Numbers of sharks and rays caught on hooks with electropositive and/or magnetic materials were not significantly different overall than those caught on J hooks alone (electropositive: 18% less, magnets: 32% less, combined: 29% less). One study found a reduction in catches of juvenile scalloped hammerhead *Sphyrna lewini* of 57% on hooks with electropositive materials, but authors note the result was inconsistent with that for adults. The systematic review summarized the effects of various actions to reduce unwanted catch, including using electropositive materials, magnetic materials, or a combination of both in longline fisheries from 10, five and one global studies respectively.

A replicated, randomized, controlled study in 2010–2013 in one area of sandy seabed in the Atlantic Ocean off South Bimini, Bahamas (7) found that great hammerhead sharks *Sphyrna mokarran* avoided bait bags with permanent magnet deterrents attached and fed less frequently compared to bait with no deterrents or bait set with non-magnetic deterrents. All data were reported on a log scale. In two of two experiments, sharks demonstrated greater avoidance behaviour to bait bags with magnet deterrents attached compared to bait bags with no deterrents or nets with non-magnetic deterrents attached. Feeding rates were lower on bait bags with magnet deterrents than bait with no deterrents or non-magnetic deterrents, between which feeding rates were similar. Sharks also exhibited higher rates of avoidance behaviour around ropes set with magnets and non-magnetic deterrents than ropes with no deterrents, around which avoidance behaviour was similar. Two experiments were undertaken between January 2010-March 2013 at depths of 3–8 m. In the first, mesh bags baited with great barracuda *Sphyraena barracuda* were set on 1 m^2 plastic apparatus with either a magnetic deterrent, a visually identical non-magnetic deterrent, or no deterrent (90 trials of 30 min). The deterrents were randomly ordered. In the second experiment, three 6 m surface ropes were set with either no vertical ropes, vertical ropes (1.5 m apart) mounted with the magnetic deterrent or ropes mounted with the non-magnetic deterrent (42 × 30 min trials). Shark behaviour was monitored from a vessel observation platform.

A replicated, controlled study in 2013–2014 in three areas of sandy seabed in the South Pacific Ocean off the coast of New South Wales, Australia (8) found that traps fitted with magnets caught fewer unwanted sharks and rays (*Elasmobranchii*), and more of the commercially targeted species snapper *Pagrus auratus*, compared to conventional traps or traps fitted with non-magnetic material. Catch rates of sharks and rays were lower in traps with magnets (0.2 ind./trap) compared to standard traps (0.3 ind./trap) and traps with non-magnetic material (0.3 ind./trap). Target catches of snapper were highest in traps with magnets (magnets: 1.1 kg/trap, standard: 0.8 kg/trap, non-magnetic: 0.98 kg/trap). In addition, the presence of sharks and rays in traps reduced target snapper catches by 38%. Between December 2013 and August 2014, a total of 1,015 traps of three different designs were set in three areas of sandy seabed at 5–102 m depth. The fish traps had a wooden frame 180 x 120 x 80 cm covered in 50 mm wire mesh with a 100 x 60 mm escape panel at the rear. Each trap design had three funnel entrances (290 x 540 mm outer and 60 x 270 mm inner) which had either four magnets (75 x 13 x 16 mm) attached to each funnel, four non-magnetic bars of the same size attached to each funnel, or no change to the standard trap.

A replicated, controlled study in 2014 in shallow inshore waters in the Tasman Sea off Tasmania, Australia (9) found that the presence of magnets reduced feeding attempts on bait by draughtboard sharks *Cephaloscyllium laticeps*, compared to bait without magnets. When magnets were present, sharks made 25 and 19 feeding attempts (for two and four magnets respectively), and 53 attempts were made with no magnets. The bait was approached but no feeding was attempted 174 times with two magnets present, 144 times with four magnets present and 123 times with no magnets present. A total of 12 trials were carried out on separate occasions between August–December 2014, each with the following three treatments placed 20 metres apart: two or four magnetic resin blocks attached to rods 0.2 m either side of jack mackerel *Trachurus declivis* bait, and two non-magnetic blocks on rods either side of the bait. Each device was placed on the seabed and recorded by video for 90 minutes.

(1) Kaimmer S. & Stoner A.W. (2008) Field investigation of rare-earth metal as a deterrent to spiny dogfish in the Pacific halibut fishery. *Fisheries Research*, 94, 43–47.
(2) Stoner A.W. & Kaimmer S.M. (2008) Reducing elasmobranch bycatch: laboratory investigation of rare earth metal and magnetic deterrents with spiny dogfish and Pacific halibut. *Fisheries Research*, 92, 162–168.
(3) Tallack S.M.L & Mandelman J.W. (2009) Do rare-earth metals deter spiny dogfish? A feasibility study on the use of electropositive "mischmetal" to reduce the bycatch of *Squalus acanthias* by hook gear in the Gulf of Maine. *ICES Journal of Marine Science*, 66, 315–322.
(4) Godin A.C., Wimmer T., Wang J.H. & Worm, B. (2013) No effect from rare-earth metal deterrent on shark bycatch in a commercial pelagic longline trial. *Fisheries Research*, 143, 131–135.
(5) McCutcheon S.M. & Kajiura S.M. (2013) Electrochemical properties of lanthanide metals in relation to their application as shark repellents. *Fisheries Research,* 147, 47–54.
(6) Favaro B. & Côté I.M. (2015) Do by-catch reduction devices in longline fisheries reduce capture of sharks and rays? A global meta-analysis. *Fish and Fisheries*, 16, 300–309.
(7) O'Connell C.P., Hyun S.Y., Gruber S.H. & He P. (2015) Effects of barium-ferrite permanent magnets on great hammerhead shark *Sphyrna mokarran* behavior and implications for future conservation technologies. *Endangered Species Research*, 26, 243–256.
(8) Richards R.J., Raoult V., Powter D.M. & Gaston T.F. (2018) Permanent magnets reduce bycatch of benthic sharks in an ocean trap fishery. *Fisheries Research*, 208, 16–21.
(9) Westlake E.L., Williams M. & Rawlinson N. (2018) Behavioural responses of draughtboard sharks (*Cephaloscyllium laticeps*) to rare earth magnets: Implications for shark bycatch management within the Tasmanian southern rock lobster fishery. *Fisheries Research*, 200, 84–92.

2.33 Use a larger mesh size

- **Forty-one studies** examined the effects of using a larger mesh size of fishing net on marine fish populations. Nine studies, and one review, were in the Atlantic Ocean[6,17,20,23,24,30,35,37,38] (UK, Portugal, USA). Eight studies were in the Aegean Sea[3,5,8,9,11,16,19,33] (Greece, Turkey). Five studies were in the North Sea[2,12,15,36,41] (UK, Netherlands, France, North Europe) and three were in the Tasman Sea[18,21,32] (Australia). Two studies were in each of the Mediterranean Sea[14,34] (Italy, Turkey), the Pacific Ocean[10,31] (USA, Chile), the Skagerrak and Kattegat[25,40] (Northern Europe) and the Gulf of Mexico[26,27] (Mexico). One study was in each of the English Channel[1] (UK), the Bering Sea[4] (USA), the Baltic Sea[7] (Finland), the Caribbean Sea[13] (Barbados), the Persian Gulf[22] (Kuwait), the Bristol Channel[28] (UK), the Barents Sea[29] (Norway) and the Arabian Sea[39] (India).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Survival (3 studies):** One of three controlled studies (one replicated and paired, and one replicated) in the Atlantic Ocean[6], Baltic Sea[7] and Bristol Channel[28] found that larger mesh sizes improved the post-capture survival of skates and rays compared to smaller meshes[28]. The other two[6,7] found similar post-capture survival in haddock[6], whiting[6] and small herring[7] between trawl nets with larger mesh and nets of smaller mesh size.
- **Condition (1 study):** One replicated, paired, controlled study in the Bristol Channel[28] reported that the condition of skates and rays at capture was better with a larger trawl codend mesh size compared to a smaller mesh.

BEHAVIOUR (0 STUDIES)

OTHER (40 STUDIES)

- **Reduction of unwanted catch (20 studies):** Fifteen of 20 replicated studies (five controlled, two paired, eight paired and controlled, one randomized and one randomized and controlled) in the North Sea[12,15,41], Skagerrak/Kattegat[25,40], Aegean Sea[8,9,16], Caribbean Sea[13], Mediterranean Sea[14,34], Atlantic Ocean[20,24,30], Tasman Sea[18,21], Gulf of Mexico[26], Pacific Ocean[31], Bering Sea[4] and the Bristol Channel[28] found that using a larger mesh size in a fishing net (various trawls, gillnets, seines and trammel nets) reduced the catches of unwanted (small/undersized, non-commercial, discarded) fish[8,12,13,14,15,16,18,20,24,25,28,31,34] or fish and invertebrates combined[9,26], compared to nets with standard/smaller mesh sizes. One study[4] found that amounts of unwanted fish were reduced with larger mesh at smaller catch sizes but were similar between large and small meshes at larger catch sizes, and one[30] found that increasing a trawl codend mesh size reduced the unwanted catch of one of two fish species compared to a standard mesh. The other three[21,40,41] found that larger mesh sized fishing nets did not typically reduce the unwanted fish catch compared to nets of smaller mesh sizes.
- **Improved size-selectivity of fishing gear (23 studies):** Nineteen of 21 replicated studies (eight controlled, four paired and controlled, three randomized and controlled, and one paired) and one review, in the North Sea[2], Aegean Sea[3,5,8,11,19,33], Baltic Sea[7], Pacific Ocean[10], Atlantic Ocean[17,23,35,37,38], Gulf of Mexico[27], Tasman Sea[32], Arabian Sea[39], Persian Gulf[22], Barents Sea[29] and the Mediterranean Sea[14,34] found that larger mesh sizes (both diamond and square) of the netting of various gear types improved the size-selectivity for all fish species assessed[2,3,5,7,8,10,14,17,19,23,27,32,33,34,35,36,37,38,39] and in one[11], for two of three fish species, compared to smaller mesh sizes. One study[22] found that size-selectivity for fish was not improved with larger mesh size in the netting of fish traps. The other[29] found that increasing the codend mesh size of trawls fitted with size-sorting escape grids resulted in similar size-selectivity of the codend for fish compared to smaller codend mesh sizes. One controlled study in the English Channel[1] found that a trawl net codend with a larger size of square mesh had similar size-selectivity for Atlantic mackerel as a smaller diamond mesh codend.

Background

Numerous fishing methods involve the use of panels of meshed netting to harvest the target species. Fishing with a net may be active (or mobile) whereby the net is dragged or hauled through the water, or it may be passive whereby the net is deployed in a fixed or semi-fixed location for a period of time. The size and shape of fish that are caught by the net is determined by the shape and the size of the mesh. As well as the target fish, fishing nets may catch immature and undersized fish or fish of unwanted species. To reduce the amount of unwanted species and/or smaller sizes caught, and thus make the net more selective, a larger size of mesh may allow unwanted individuals to escape capture while retaining the commercially targeted species or sizes (Burgos-León *et al.* 2009).

Note: The mesh sizes reported here are typically the 'nominal' measurements of the mesh sizes' given in the studies, i.e. the approximate intended size of the meshes in a net. The actual mesh size, usually measured as the average size of several meshes stretched under tension, may vary depending on factors like the configuration of the knots or twine characteristics. In addition, during use, the effective size (or gap opening) of the meshes may also change with how the net is deployed (e.g. towing speed for trawl nets) and the size of the catch.

Evidence for interventions describing other modifications to fishing net mesh (size and/or shape) is summarized under *'Fishing gear modification – Use a square mesh instead of a diamond mesh codend on trawl nets; Modify gillnet or entangling (trammel/tangle) net configuration'* and *'Rotate the orientation of diamond mesh in a trawl net'*.

Burgos-León A., Pérez-Castañeda R. & Defeo O. (2009) Discards from the artisanal shrimp fishery in a tropical coastal lagoon of Mexico: spatio-temporal patterns and fishing gear effects. *Fisheries Management and Ecology*, 16, 130–138.

A controlled study in 1990 of an area of midwater in the western English Channel, UK (1) found that a pelagic trawl net with a square mesh codend of larger mesh size caught similar sizes of Atlantic mackerel *Scomber scombrus* compared to a conventional smaller sized diamond mesh codend, and thus there was no difference in size-selectivity. The length frequencies of mackerel caught were similar between a 60 mm square mesh codend (range: 8–31 cm, midpoint: 13 cm) and a 40 mm diamond mesh codend (range: 7–32 cm, midpoint: 13 cm). In January–February 1990, a total of 14 trawl deployments were undertaken in the western English Channel from a 64 m commercial fishing vessel. Nine trawl deployments used an experimental codend of 60 mm square mesh, and five deployments used a conventional 40 mm diamond mesh codend. The experimental codend was 4 m shorter than the conventional codend, with four panels rather than the conventional two. Each trawl design was deployed alternately when shoals of mackerel were visible in the water. All mackerel caught in each trawl were counted and measured.

A replicated, controlled study in 1986–1988 on bottom fishing grounds in the northern and central North Sea, UK (2) found that larger mesh size trawl codends and seine nets had improved size-selectivity for haddock *Melanogrammus aeglefinus*, whiting *Merlangius merlangus,* and for seines Atlantic cod *Gadus morhua,* compared to the standard and smaller mesh sizes. Across both gear types, the length at which fish had a 50% chance of escape was greater with a 100 mm mesh (haddock: 19–32 cm, whiting: 23–39 cm, cod: 23–36 cm) than 90 mm mesh (haddock: 15–28 cm, whiting: 19–34 cm, cod: 19–30 cm) which in turn was greater than an 80 mm mesh (haddock: 10–24 cm, whiting: 14–29 cm, cod: 12–24 cm). No cod were caught in the trawl nets. Commercial trawl and seine nets were tested with 100 mm, 90 mm (the minimum mesh size in force in the commercial fishery), and 80 mm mesh codends. Three surveys were carried out on two commercial vessels in the North Sea in 1986–1988, two with a trawl net and one with a seine net. Covers were fitted over the codends to catch fish escaping through the meshes. Thirty-five trawl deployments were made with the 100 mm mesh and 36 with each of the 90 mm and 80 mm meshes. For the seine nets, a total of 94 (100 mm mesh), 113 (90 mm mesh) and 121 (80 mm mesh) deployments were made. All fish in the codends and covers were identified and their lengths measured.

A replicated study in 1992–1993 of an area of seabed in the Aegean Sea, Greece (3: same experimental set-up as 5) found that increasing the mesh size of a gillnet improved the size-selectivity of annular seabream *Diplodus annularis* and striped red mullet *Mullus* *surmuletus* compared to smaller mesh sizes. For both species, the average length of fish caught was greater for the largest mesh size of 23 mm (seabream: 119 mm, mullet: 165 mm) than a 21 mm mesh (seabream: 109 mm, mullet: 150 mm), a 19 mm mesh (seabream: 98 mm, mullet: 136 mm) and a 17 mm mesh (seabream: 88 mm, mullet: 122 mm). In addition, total catch decreased with increasing mesh size for seabream (23 mm: 121, 21 mm: 352, 19 mm: 123, 17 mm: 126 fish/1000 fathoms) and mullet (23 mm: 102, 21 mm: 73, 19 mm: 116, 17 mm: 352 fish/1000 fathoms). Fishing trials took place at 15 sites in the South Euboikos Gulf between August 1992 and April 1993. Nets were set two hours before sunrise and hauled two hours after sunrise at depths from 18–60 m. Gillnets with mesh sizes of 23 mm, 21 mm, 19 mm or 17 mm were switched monthly. Weight and length of captured fish were recorded.

A replicated, randomized, controlled study in 1994 of an area of midwater in the Bering Sea, Alaska, USA (4) found that trawl codends of larger mesh size reduced the catches of undersized walleye pollack *Theragra chalcogramma* at smaller catch sizes but not larger, compared to a conventional smaller mesh codend. Data were reported as percentage catch composition. In catches <40 tonnes, the average percentage of undersized (<36 cm) pollock caught was lower with both larger mesh codends: a 88 mm mesh (88 mm: 17%, standard: 38%) and a 113 mm mesh (113 mm: 7%, standard: 24%), compared to a standard smaller mesh codend. However, in catches ≥ 40 tonnes the percentage of undersized pollack was similar in all codends (30–45%). Between July and August 1994, trawling using different codend types (including different mesh material and codends with square mesh panels of different sizes – see paper for data) was conducted during daylight hours (maximum duration of four hours) off Unimak Island. A total of 60 deployments were completed by four vessels in a randomized block design with sequential tows using either one of two experimental codends (113 mm and 88 mm diamond mesh) and a standard diamond mesh codend (85 mm inside layer) that was double-layered with the effect of having a smaller mesh than the experimental nets. All catches were sorted and counted.

A replicated study in 1992–1993 of an area in the Aegean Sea, Greece (5: same experimental set-up as 3) found that increasing the mesh size of a gillnet improved the size-selectivity of unwanted red mullet *Mullus barbatus,* common pandora *Pagellus erythrinus,* axillary seabream *Pagellus acarne* and picarel *Spicara flexuosa* compared to smaller mesh sizes. For all species, the average length of fish caught was greater for the largest mesh size of 23 mm: for mullet (179 mm), pandora (144 mm), seabream (149 mm) and picarel (176 mm), than a 21 mm mesh (mullet: 164, pandora: 132, seabream: 136, picarel: 161 mm), a 19 mm mesh (mullet: 148, pandora: 119, seabream: 123, picarel: 146 mm) and a 17 mm mesh (mullet: 133, pandora: 107, seabream: 110, picarel: 130 mm). In addition, total fish catch typically decreased with increasing mesh size (23 mm: 782, 21 mm: 820, 19 mm: 3,439, 17 mm: 326 fish/1000 fathoms). Fishing trials took place at 15 sites in the South Euboikos Gulf between August 1992 and April 1993. Nets were set two hours before sunrise and hauled two hours after sunrise at depths from 18–60 m. Gillnets with mesh sizes of 23 mm, 21 mm, 19 mm or 17 mm were switched monthly. Weight and length of captured fish were recorded.

A controlled study in 1993 of bottom fishing grounds in the Atlantic Ocean off Northwest Scotland, UK (6) found that increasing the mesh size of trawl codends did not affect the post-release survival of haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus*. Post-capture survival rates were not statistically different between codend mesh sizes for haddock (110 mm: 85–89%, 100 mm: 73–83%, 90 mm:

79–82%, 70 mm: 48–67%) and whiting (110 mm: 83–86%, 100 mm: 83–86%, 90 mm: 73–78%, 70 mm: 52–60%). In addition, survival was affected by fish length, with higher survival in larger fish. Trawl codends of 110 mm, 100 mm, 90 mm or 70 mm mesh were deployed one at a time in summer 1993. Covers attached over each codend retained haddock and whiting escaped through the meshes. The escaped fish were put into three cages per mesh size (two for 90 mm mesh) on the seabed, and fed and monitored for 60 d. Length and survival of fish was recorded. Details of number and duration of hauls were not reported.

A replicated, controlled study in 1992 in an area of seabed in the Baltic Sea, Finland (7) found that a larger mesh size increased the size at which herring *Clupea harengus* could escape from a pelagic trawl net, and for smaller fish post-capture survival was similar between mesh sizes. The numbers at length of herring between 12–17 cm that escaped from a 36 mm codend ranged from 20–1,200, whereas almost no fish of these sizes escaped from a 26 mm mesh (data were not tested statistically). However, there was no difference in average percentage mortality of small (<12 cm) herring escapees between the 36 mm and 26 mm mesh codends and compared to herring escaping from an open codend (data reported as statistical model results). A total of 37 trawl deployments of 15–30 minutes were made using three codend types (36 mm, 26 mm and open) in April–June 1992 from a commercial trawler. A small mesh (14 mm) codend cover retained the escaping fish. After each deployment escaped herring were released into a separate cage (average 760 herring/cage) suspended 7–17 m below the surface. Cages were recovered in blocks at intervals between 1.5–9 days and mortality recorded.

A replicated, randomized, controlled study in 1993–1994 in two areas of seabed in the Aegean Sea, Greece (8: same experimental set-up as 9) found that increasing the mesh size of diamond mesh trawl codends improved size-selectivity and reduced the undersized catches of European hake *Merluccius merluccius* compared to codends with conventional mesh size. The length at which hake had a 50% chance of escape was 13.8 cm for 20 mm diamond mesh and 4.2 cm for 14 mm diamond mesh codends. The percentage of undersized hake retained was lower in the larger diamond mesh (20 mm: 52%, 14 mm: 61%). In October 1993 and March 1994, experimental trawl deployments were conducted in two areas (Trikeri Channel and North Euboikos Gulf, twelve stations in total) using a trawl fitted with either a 20 mm diamond mesh codend or a conventional 14 mm diamond mesh codend used by the fishery (12 hauls of each at each sites). Codend type was randomly allocated and small mesh (10 mm) covers retained fish escaping through the meshes. For each deployment, the total number and weight caught by species in the codends and covers were recorded. Lengths of the main species were subsampled.

A replicated, randomized, controlled study in 1993–1994 in two areas of coastal water in the Aegean Sea, Greece (9: same experimental set-up as 8) found that trawl codends of larger mesh size allowed the escape of more unwanted individuals and species (fish and invertebrates) compared to a conventional diamond mesh codend of smaller mesh size. For both sampling periods and for all species (fish and invertebrates combined), the average number of individuals (20 mm: 1,486–8,167 ind/h, 14 mm: 204–855 ind/h) and species (20 mm: 16 species, 14 mm: 9 species) that escaped was higher with the larger mesh compared to the standard. The ratios of commercial/non-commercial retained catch were higher in 20 mm diamond mesh codends (0.60–1.31) than in 14 mm diamond mesh codends (0.27–0.29). In October 1993 and March 1994, experimental trawl deployments were conducted in two areas (Trikeri Channel and North Euboikos Gulf, twelve stations in total) using a trawl fitted with either a 20 mm diamond mesh codend or a conventional 14 mm diamond mesh codend used by the fishery (12 hauls of each at each station). Codend type was randomly allocated and small mesh (10 mm) covers retained fish escaping through the meshes. For each deployment, the total number and weight caught by species in the codends and covers were recorded.

A replicated, randomized, controlled study in 1988–1990 of bottom fishing grounds in the Pacific Ocean, USA (10) found that increasing the mesh size in trawl net codends improved the size-selectivity of rockfishes *Sebastidae* and flatfishes *Pleuronectidae* and *Bothidae*, for both diamond and square mesh. For five rockfish species, the lengths at which fish had a 50% chance of escape increased with increasing mesh size for both diamond (140 mm: 42–46 cm ,127 mm: 38–41 cm, 114 mm: 30–37 cm) and square meshes (127 mm: 34–44 cm, 114 mm: 29–42), compared to the standard 114 mm mesh size. For five flatfish species, the lengths at which fish had a 50% chance of escape also increased with increasing mesh size (diamond, 140 mm: 35–43 cm, 127 mm: 30–41 cm, 114 mm: 28–37 cm; square, 127 mm: 31–37 cm, 114 mm: 25–32). See original paper for species specific data. Decreases in the estimated percentages of discarded fish with increasing mesh size were found for eight of the ten species, but these differed between diamond and square meshes (data not statistically tested). Data were collected in 1988–1990 by the West Coast Groundfish Mesh Size survey. Experimental diamond mesh codends with mesh sizes of 140 mm, 127 mm, 114 mm, and 76 mm (the standard to sample all lengths of fish), and square mesh codends of 114 mm and 127 mm were tested. Codends were deployed in randomized blocks of two or three codends, together with the standard, during each fishing season by commercial trawling vessels.

A replicated, controlled study in 1995–1996 in coastal waters of the Aegean Sea, Turkey (11) found that increasing the codend mesh size of a bottom trawl improved the size-selectivity of three fish species, for both diamond and square mesh. The length at which fish had a 50% chance of escape was greater for the largest mesh sizes (across both square and diamond mesh) compared to the smallest: for red mullet *Mullus barbatus* (44 mm: 12–13 cm, 40 mm: 11–12 cm, 36 mm: 10–11 cm), annular seabream *Diplodus annularis* (48 mm: 11–12 cm, 44 mm: 8–9 cm, 40 mm: 8 cm, 36 mm: 6–7 cm) and axillary seabream *Pagellus acarne* (44 mm: 12–13 cm, 40 mm: 11 cm, 36 mm: 9–10 cm). The effect at the intermediate mesh sizes varied however between species and codend types (see paper for data). Data were collected from 85 trawl deployments by a research vessel from October 1995 for 12 months. Eight different codends of diamond and square mesh with four different mesh sizes were tested: 48 mm, 44 mm, 40 mm and 36 mm. Deployments were 1 h at 30–110 m depth. A small mesh (24 mm) cover attached to the codend collected catch escaping through the meshes. Fish caught in both the codends and cover were sorted by species, counted and lengths recorded.

A replicated, randomized study in 1995 of bottom fishing grounds in the central North Sea, north Europe (12) found that increasing the mesh size in a gillnet caught fewer unwanted small fish compared to smaller mesh sizes. For all three species, average catch length increased and catch numbers of undersized fish decreased between the largest (118 mm) and smallest (81 cm) mesh sizes: for sole *Solea solea* (length, largest mm: 31 cm, smallest: 27 cm; undersized, largest: 26 fish, smallest: 407 fish), plaice *Pleuronectes platessa* (length, largest mm: 40 cm, smallest: 24 cm; undersized, largest: 87 fish, smallest: 274 fish) and cod *Gadus morhua* (length, largest mm: 41 cm, smallest: 27 cm; undersized, largest: 20 fish, smallest: 94 fish). Fishing took place during May and June 1995 with nets deployed overnight. A total of 24 gillnet deployments containing 10 fleets of seven nets, each with a different mesh size (118 mm, 113 mm, 105 mm, 99 mm, 92 mm, 86 mm and

81 mm) were set overnight. The order of the nets in a fleet was randomized. Catch was sorted and fish lengths recorded.

A replicated, paired, controlled study in 1986–1996 of three coral reefs in the Caribbean Sea, Barbados (13) found that coral reef fish traps with larger mesh size reduced the catches of smaller and immature fish, compared to conventional traps of smaller mesh size. Across trials, average fish size was greater in large mesh traps of 5.5 cm maximum aperture than in conventional commercial traps of smaller 4.1 cm maximum aperture (large: 17 cm, conventional: 15–16 cm). The percentage of immature fish was also lower in the larger mesh traps (large: 4–16, conventional: 8–20%). However, catch rates of larger fish (body depth >5.5 cm) were also lower in the large mesh traps (14–19 fish/trap) than conventional traps (30 fish/trap). Data were collected during two separate experiments in May 1986, 1990, 1991 and 1996, and February–June 1996. Two mesh sizes of Antillean arrowhead traps were tested: large mesh traps (mesh of maximum aperture 5.5 cm) and traps with the mesh size used in the Barbados commercial fishery (4.1 cm maximum aperture). In the experiment, traps were placed in pairs and fished for 1–4 days (46 traps/mesh size at three locations). In the second, 12 traps (three/mesh size) were randomly placed and fished for five days.

A replicated, paired study in 1996–1997 in two areas of sandy-muddy seabed in the Mediterranean Sea, Italy (14) found that an increase in the mesh size of set nets (gill and trammel) improved size-selectivity and reduced catches of small striped seabream *Lithognathus mormyrus* than a smaller mesh size. Across areas and nets, net selectivity (measured as optimal catch size) and average seabream length in catches increased with the larger 70 mm mesh size compared to the smaller 45 mm mesh size (selectivity, large: 26 cm, small: 17 cm; average length, large: 23–26 cm, small: 16–18 cm). In addition, the authors reported that the net selectivity for both mesh sizes was higher than the size at first maturity of striped seabream (14 cm), and that there were hardly any individuals under this size caught in the larger mesh, and between <1–3% for the smaller mesh size. Data were collected between March 1996 and June 1997 from set net deployments in the Adriatic Sea (29 trials) and Ligurian Sea (43 trials). Two mesh sizes (45 mm and 70 mm) mesh were tested simultaneously on each of three set net gears: a gillnet, a monofilament trammel net and a standard commercial trammel net. The three nets (each with two different mesh sizes) were tied end to end and the position of each gear changed for each trial. Nets were lowered into shallow (4–15 m) water at dusk and retrieved the following dawn. All fish were identified, and individual lengths measured.

A replicated, paired, controlled study in 1989 of bottom fishing grounds in the North Sea, Netherlands (15) reported that larger mesh size trawl codends caught fewer non-target small European smelt *Osmerus eperlanus* and long rough dab *Hippoglossoides platessoides* compared to smaller mesh sizes. Results were not tested for statistical significance. Codends with 20 mm mesh size caught fewer small smelt than 12 mm mesh codends (data reported as graphical analysis), and 155 mm mesh codends caught fewer small long rough dab than 39 mm mesh codends (data reported as graphical analysis). In addition, it was found that fish of increasing length were caught in increasingly higher numbers in the larger mesh codends compared to the smaller mesh, indicating that larger cod did not enter the smaller mesh codends at the same rate as the larger mesh codends. In September 1989, four 15 min deployments were undertaken using 20 mm and 12 mm mesh codends simultaneously in a trouser trawl. The 155 mm and 39 mm mesh codends were also tested simultaneously with a trouser trawl (published data – see paper for details). The lengths of captured fish were measured. Full gear specifications are given in the original paper.

A replicated, controlled study in 1997–1998 in an area of seabed in the Aegean Sea, Greece (16) reported that larger mesh sizes in a gillnet caught fewer unwanted small fish compared to smaller mesh sizes. Results were not tested for statistical significance. The most frequent length of fish caught in nets of increasing mesh size between 22 mm and 28 mm mesh increased for seven of seven species, for two of two species between 22 mm and 24 mm mesh and for one of one species between 22 mm and 26 mm mesh (see original paper for species individual data). A total of 42 fishing trials took place in September 1997–October 1998 using gillnets of 22 mm, 24 mm, 26 mm and 28 mm mesh size. Nets of each mesh size were set in lengths of 1,000 m (0.30 mm diameter multi-monofilament nylon) and at depths of 4–90 m in traditional fishing grounds.

A replicated study in 1992 of bottom fishing grounds in the Atlantic Ocean off Portugal (17) found that trawl nets of larger codend mesh size had improved size-selectivity for fish compared to smaller mesh sizes. The length at which fish had a 50% chance of escape was greater for the larger mesh sizes compared to the smallest, for hake *Merluccius merluccius* (80 mm: 19 cm, 70 mm: 19 cm, 65 mm: 17 cm), blue whiting *Micromesistius poutassou* (80 mm: 25 cm, 70 mm: 25 cm, 65 mm: 23 cm) and four spot megrim *Lepidorhombus boscii* (80 mm: 21 cm, 70 mm: 18 cm, 65 mm: 17 cm). A total of 50 deployments of three different diamond mesh codends (80 mm, 70 mm and 65 mm; 13–19 hauls/mesh size) were carried by a research vessel in August 1992. Trawl nets were towed at 3.5 knots for 60 minutes. All fish escaping through the meshes of the codends were collected by a cover fitted over the trawl. All fish were weighed. The lengths of all hake and megrim were measured, and mackerel and whiting lengths subsampled.

A replicated, controlled study in 2003 in shallow, pelagic waters in the Tasman Sea off New South Wales, Australia (18) found that seine nets of larger mesh size caught fewer unwanted immature garfish *Hyporhamphus australis* compared to smaller and conventional mesh sizes. The proportion and number of immature (<20 cm length) garfish in the total catch decreased with increasing mesh size and was 7% (198 fish) for 32 mm mesh, 15% (1,768 fish) for 28 mm mesh, 53% (2,007 fish) for 25 mm mesh, and 74% for conventional 12 mm mesh (10,792 fish). Sampling took place from a commercial fishing vessel between March and April 2003. A commercial seine net was split into four sections in which each tested mesh size was installed (32 mm, 28 mm, 25 mm and 12 mm) and position alternated between days. Fish were sighted and aggregated using fish bran food. Once feeding, the net was deployed, and the vessel encircled the net around the fish to be hauled. On deck, fish lengths were measured to the nearest half centimetre.

A replicated, controlled study in 2002 in an area of seabed in Izmir Bay in the Aegean Sea, Turkey (19) found that using a larger mesh size codend and different netting material in a trawl net improved the size-selectivity of annular sea bream *Diplodus annularis* and common pandora *Pagellus erythrinus* compared to a smaller commercial mesh size and netting type. For sea bream, irrespective of twine type, the length at which fish had a 50% chance of escape was higher in a 44 mm mesh codend (10.3 cm) compared to the standard 40 mm (8.8 cm) and a 36 mm mesh (8.4 cm) codend. For pandora, the length at 50% escape was also greater with the larger mesh than the standard (44 mm: 13.8 cm, 40 mm: 10.8 cm). However, compared to the standard it was also greater in a smaller mesh of a different twine type (36 mm: 12.4 cm). Data were collected from 23 experimental trawl deployments conducted from a research vessel in February and March 2002. Three codend types were tested: 44 mm and 36 mm mesh size multi-filament polyamide netting, and a commercially used 40 mm multi-monofilament polyethylene netting (see paper for specifications). Small mesh (24 mm) codend covers retained escaping fish. Tow duration was 45 minutes with an average tow speed of 2.4 knots.

A replicated, controlled study in 1994–1995 of eight areas of seabed in the Atlantic Ocean, off Portugal (20) found that larger mesh size gillnets caught less unwanted non-commercial fish catch compared to smaller mesh sizes. The proportions of non-commercial fish catch typically decreased with increasing mesh size, in both number (90 mm: 0.12, 80 mm: 0.07, 70 mm: 0.10, 60 mm: 0.21, 40 mm: 0.22) and weight (90 mm: 0.04, 80 mm: 0.02, 70 mm: 0.04, 60 mm: 0.11, 40 mm: 0.19). A total of 88 different fish species were caught, of which most were low value or non-commercial (see original paper for individual data for the most caught species). Between April 1994–September 1995, a total of 78 sets of gillnet were deployed (1,155 fishing hours, 24–250 m depth) using up to five different mesh sizes: 90 mm (1995 only), 80 mm, 70 mm, 60 mm and 40 mm. Nets were 60 m long and 3 m deep. Fish catch was sorted by species, and lengths and weights recorded.

A replicated, paired, controlled study in 2004 of two areas of seabed in the Tasman Sea off New South Wales, Australia (21) found that a larger size of square mesh in trawl codends did not typically reduce the catches of discarded whiting *Sillago* spp. compared to a smaller mesh size, however both caught less than a standard diamond mesh. All data were reported as statistical model results. Catch number of all discarded whiting was lower in a 41 mm square mesh than a 35 mm square mesh, and both were lower than a standard 41 mm diamond mesh, for one of two vessels only. By weight, total discarded whiting was similar between the two square mesh sizes, but both were lower compared to the standard diamond mesh, for one of two vessels only. Target king prawn *Penaeus plebejus* catches were similar across codend designs, although weight and number of legally sized whiting were lower in larger square mesh. In April-December 2004, a total of eight deployments/trawl codend type were carried out on two commercial prawn trawlers rigged with three trawls. Two square mesh codends (41 mm and 35 mm) were compared with a conventional 41 mm diamond mesh codend. Each square mesh codend was deployed simultaneously with the standard diamond codend in paired tows using the outer two trawls. All codends also had a square mesh escape panel. See original study for gear details.

A replicated, paired, controlled study in 2001–2002 at three intertidal sites in the Persian Gulf, Kuwait (22) found that increasing the mesh size in fish traps (hadrah) did not typically improve the size-selectivity for a variety of fish species compared to a smaller conventional mesh size. The length at which fish had a 50% chance of escape was greater in traps with larger mesh sizes (51 mm or 25 mm) compared to conventional traps (19 mm) in only six of 40 comparisons, similar between mesh sizes in 31 comparisons, and smaller in the larger mesh sizes in three comparisons (see original paper for individual data for 25 fish species/groups). Sampling was carried out from October 2001 to December 2002 at three sites (Failakah, AlBaq'sh and Abu Hasaniyah). At each location, two traps were deployed: one of two experimental traps consisting of either 25 mm (AlBaq'sh and Abu Hasaniyah) or 51 mm (Failakah) mesh size, and a conventional trap of 19 mm mesh size. The two traps were positioned near to one another and fish were removed after 24 h and length recorded. A total of 153 samples were collected at Failakah, 38 from AlBaq'sh and 30 from Abu Hasaniyah.

A replicated, randomized, controlled study in 2003 in an area of seabed in coastal waters in the Gulf of Maine, Atlantic Ocean, USA (23) found that increasing the mesh size on trawl net codends, for both diamond and square mesh, typically improved the size-selectivity of five fish species compared to conventional smaller mesh sizes. For diamond and square meshes, the size at which fish had a 50% chance of escape typically increased with increasing mesh size for five of five species: cod *Gadus morhua* (diamond, large: 66 cm, intermediate: 59 cm small: 52 cm; square, large: 69 cm, small, 59 cm), haddock *Melanogrammus aeglefinus* (diamond, large: 61 cm, intermediate: 55 cm small: 50 cm; square, large: 57 cm, small, 54 cm), long rough dab *Hippoglossoides platessoides* (diamond, large: 39 cm, intermediate: 40 cm small: 36 cm; square, large: 35 cm, small, 33 cm), yellowtail flounder *Limanda ferruginea* (diamond, large: 42 cm, intermediate: 40 cm small: 38 cm; square, large: 38 cm, small, 34 cm), and witch flounder *Glyptocephalus cynoglossus* (diamond, large: 46 cm, intermediate: 43 cm small: 40 cm; square, large: 40 cm, small, 36 cm). For haddock and long rough dab, the difference between the large and intermediate diamond mesh sizes was not significant. Data were collected from 86 trawl deployments on a commercial fishing vessel in May–July 2003. Five codends were tested, three diamond mesh (178 mm, 165 mm and 152 mm mesh size) and two square mesh (178 mm and 165 mm mesh size). The existing minimum mesh was 165 mm for both diamond and square. The five codends were tested randomly in a preselected order with each being tested for up to six consecutive tows. Each codend had a small mesh cover to collect fish escaping through the meshes. Upon hauling, fish were sorted by species and individual lengths recorded.

A replicated, controlled study in 2005 in three areas of seabed in the northeast Atlantic Ocean off Cornwall, UK (24) found that increasing the mesh size of bottom gillnets resulted in fewer unwanted small hake *Merluccius merluccius* compared to smaller mesh sizes. The lengths at which hake were caught most frequently increased with increasing gillnet mesh size (140 mm: 93–96 cm, 120 mm: 80–82 cm, 100 mm: 67–69 cm, 80 mm: 53–55 cm. Experimental gillnetting was undertaken over three fishing trips. Twenty-four bottom-set gillnets deployments were made, with six nets of each mesh size (140 mm, 120 mm – the mesh size most commonly used in the fishery, 100 mm and 80 mm) deployed during each trip. Gill nets were 5.5 m high and 107 m long. The headrope was floated every 180 cm and the footrope was weighted with lead weights. During each trip, nets were soaked for 12–37 h over seven days.

A replicated, paired, controlled study in 2003 in an area of seabed in the Skagerrak and Kattegat, Northern Europe (25) found that increasing the mesh size of a diamond mesh prawn trawl codend reduced the catches of undersized and discarded fish compared to a conventional smaller mesh size. For seven of seven commercial species, total catch numbers of undersized fish were reduced with the larger mesh size by between 59–92% compared to the standard mesh size (large: 1–130 fish, standard: 12–313 fish; see paper for species individual data). The total weight of other discarded fish was also lower with the larger mesh (large: 445 kg, 903 kg). Data were collected in August and September 2003, from 21 paired trawl deployments of an experimental 120 mm diamond mesh codend and an industry standard 90 mm diamond mesh codend. Deployments used a three-warp towing system and codends were swapped between sides of the vessel every sixth tow. Average tow time was 7 h at a speed of 2.5 knots.

A replicated, paired, controlled study (year not stated) in an estuarine lagoon in the Gulf of Mexico, off Mexico (26: same experimental set-up as 27) found that increasing the mesh size in a shrimp trawl codend reduced the overall unwanted catch (fish and invertebrates combined) compared to a conventional mesh size codend. Total discarded catch was lower with a 2.5 cm mesh size (0.9 individuals/245 m^2) compared to a 1.3 cm mesh (3.2 individuals/245 m^2). In addition, the 2.5 cm mesh size caught fewer unwanted smaller individuals than the 1.3 cm mesh size for six of the eight most important species. Target shrimp *Farfantepenaeus* spp. catch was also lower with the larger mesh size than the conventional mesh size (1.0 vs 2.7 individuals/245 m^2). Three sites 3–5 km apart in the Celestun Lagoon (shallow, tidal) were sampled in three seasons (March-May, June-October and November-February, years unspecified). Two bottom nets (shrimp triangle) were fished simultaneously with different mesh-size codends: 2.5 cm mesh and a conventional 1.3 cm mesh used in the shrimp fishery. Three replicate samples were taken in each case. Unwanted fish and invertebrate catch and shrimps were sorted by species, counted and lengths measured.

A replicated, paired, controlled study in 2000 in an estuarine lagoon in the Gulf of Mexico, off Mexico (27: same experimental set-up as 26) found that increasing the mesh size in a shrimp trawl codend improved the size-selectivity for fish, compared to a smaller conventional mesh size. The length at which fish had a 50% of escape was greater with a larger 25 mm mesh codend than a standard 13 mm mesh for four of the five most commonly caught species: lined sole *Achirus lineatus* (large: 31 mm, standard: 15 mm), Mayan cichlid *Cichlasoma urophthalmus* (large: 42 mm, standard: 21 mm), silver jenny *Eucinostomus gula* (large: 51 mm, standard: 21 mm) and pinfish *Lagodon rhomboides* (large: 53 mm, standard: 24 mm). The other species, American silver perch *Bardiella chrysoura* was only caught with the 13 mm mesh. Fishing was carried out in February, April and September 2000 at three sites in the Celestun Lagoon. At each site two bottom nets were deployed simultaneously: an experimental 25 mm mesh net and a conventional 13 mm mesh net. Nets were cone-shaped with openings of 2.45 m width and 1.25 m height. Small mesh covers over each codend collected fish escaping through the meshes. At each site, nets were hand-hauled 100 m, parallel to the shore at 1.2 m depth. All catch was sorted and fish lengths recorded.

A replicated, paired, controlled study in 2009 in an area of fished seabed in the Bristol Channel, UK (28) reported that bottom trawls fitted with a larger mesh size, both diamond and square mesh shapes, typically had lower catches of discarded fish and improved overall survival and condition of skates and rays *Batoidea* post-capture, compared with a conventional 80 mm diamond mesh codend. Results were not tested for statistical significance. For diamond mesh, a larger mesh size had lower discarded catch numbers of five of seven fish species/groups compared to the standard size (large: 13–1,544 fish, standard: 109–5,371 fish) and two were higher (large: 11–313 fish, standard: 9–215 fish). For a square mesh of the same larger size, the discarded catch of all seven species/groups was reduced compared to the standard diamond mesh (large: 0–2,091 fish, standard: 3–5,082 fish). See original paper for species individual data. For 1,539 skates/rays caught, the proportion assessed as in good health (associated with improved post-release survival) was 47% and 34% in the large square and diamond meshes respectively, and 25% in the 80 mm diamond mesh. Post-capture survival (after 48 h) of 278 small-eyed skate *Raja microocellata* ranged from 59–67% in the larger meshes and 55–57% in the standard mesh size. Data were collected from 32 paired trawl deployments in the Bristol Channel in June–July 2009. Trawls fitted with either an experimental 100 mm diamond or 100 mm square mesh codend were towed simultaneously with a conventional 80 mm diamond mesh codends (16 hauls each). Small-eyed skate from each codend were assigned health scored and monitored for 48 h.

A replicated, controlled study in 2009 of an area of seabed in the Barents Sea off the coast of northern Norway (29) found that increasing the mesh size of a trawl codend fitted with a size-sorting escape grid, resulted in a similar size-selectivity of cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* compared to a codend with a conventional smaller mesh size. The average length at which fish had a 50% chance of escape was similar between a larger (140 mm) diamond mesh codend and a smaller (135 mm) diamond mesh codend for both cod (large: 49 cm, small: 46 cm) and haddock (large: 45 cm, small: 43 cm). Data were collected in March 2009 from 28 deployments on a survey vessel: 12 hauls with a 140 mm diamond mesh codend and 16 with a 135 mm diamond mesh codend. Both trawl nets also had a size-sorting escape grid ("Sort-V", 55 mm bar spacing, upper escape opening) in front of the codend (see original paper for gear specifications). Covers fitted over both the grid escape opening and codend collecting fish escaping from these areas. The lengths of cod and haddock >30 cm in codend and cover catches were recorded.

A replicated, paired, controlled study in 2008 of an area of seabed in the Atlantic Ocean, USA (30) found that increasing the codend mesh size on a bottom squid *Loligo* trawl reduced the unwanted catch of one of two fish species, compared to a conventional mesh size. Catch rates of Atlantic butterfish *Peprilus triacanthus* were lower with the larger 65 mm mesh compared to the standard 50 mm mesh (large: 400 kg/km^2, standard: 809 kg/km^2), and more than half (54%) of the reduction in catch consisted of smaller and more likely to be immature fish. For silver hake *Merluccius bilinearis*, catch rates were not significantly different (the authors noted this may have been due to the small sample size and highly variable catches) between mesh sizes (large: 117 kg/km^2, standard: 194 kg/km^2). However, most (86%) of the reduction in hake catch with the larger mesh consisted of fish smaller than the average size at maturity. Data were collected in September–October 2008, from 65 paired trawl deployments on a fishing vessel using a twin trawl. On one side an experimental 65 mm codend was fished and on the other a conventional 50 mm codend. Trawls were towed for 1 h at 60–134 m depth. Total catch weights, numbers and individual lengths of each species were recorded.

A replicated study in 2008–2009 in an area of fished seabed in the Pacific Ocean off Chile (31) found that crustacean trawls with larger mesh codends allowed more unwanted fish to escape than smaller mesh codends. The average percentage number of escaped fish was higher using larger 70 mm mesh compared to 56 mm mesh: in four of four comparisons for Chilean hake *Merluccius gayi gayi* (3–38 vs 0–1%) and bigeye flounder *Hippoglossina macrops* (8–27 vs 0–1%), and in one of one comparison for Aconcagua grenadier *Coelorinchus aconcagua* (44 vs 3%), cardinalfish *Apogonidae* (51 vs 4%) and eelpout *Zoarcidae* spp. (96 vs 26%). A total of 101 trawl deployments were made by three commercial vessels targeting three different crustacean species during two experiments in December 2008 and June–July 2009. Trawls were fitted with either a 70 mm diamond or square mesh codend and compared with deployments of a 56 mm diamond mesh codend. Small mesh covers over each codend collected the fish escaping through the meshes.

A replicated study in 2011 in an area of seabed in the Tasman Sea, Tasmania, Australia (32) found that using a larger codend mesh size in a trawl net improved the size-selectivity of tiger flathead *Neoplatycephalus richardsoni* and sand flathead *Platycephalus bassensis*, compared to a smaller codend mesh size. The length at which flatheads (both species combined) had a 50% chance of escape was greater with a larger 90 mm mesh codend compared to a smaller 70 mm mesh codend (large: 307 mm, small: 294 mm).

Length at maturity for female tiger flathead was 337 mm and 247 mm for female sand flathead. Fishing trials were done on trawl grounds off north-east and eastern Tasmania between May and July 2011 using a bottom (demersal) fish trawl. Alternate deployments of two diamond-mesh codends of 90 mm (nine hauls) and 70 mm (eight hauls) mesh size were carried out. A cover attached over each codend collected fish escaping through the meshes. Catch was sorted by species and flathead length measured.

A replicated, controlled study (year not stated) in an area of seabed in a coastal bay in the Aegean Sea, Turkey (33) found that larger codend mesh sizes, both diamond and turned (90°) meshes, in a bottom trawl net improved the size selectivity of red mullet *Mullus barbatus*, common pandora *Pagellus erythrinus* and annular sea bream *Diplodus annularis* compared to smaller mesh codends. For both the standard diamond mesh and diamond mesh turned by 90°, the average length at which fish had a 50% chance of escape was greater as mesh size increased: for mullet (50 mm: 15–18 cm, 44 mm: 11–15 cm, 40 mm: 9–12 cm), pandora (50 mm: 15 cm, 44 mm: 11–13 cm, 40 mm: 9–10 cm) and bream (50 mm: 12 cm, 44 mm: 10 cm, 40 mm: 9 cm). In addition, the lengths of 50% escape were higher in the turned diamond mesh compared to the standard diamond for mullet and pandora, and similar for bream. Data were collected from 61 trawl deployments (30 min) in Izmir Bay in December-May (years unspecified), using five different experimental codends: 50 mm diamond mesh (10 hauls), 44 mm mesh, standard (10 hauls) and turned 90° diamond mesh (17 hauls), and 40 mm mesh, standard (11 hauls) and turned diamond (13 hauls). Small mesh (24 mm) covers attached over each codend collected fish escaping through the meshes. The species and lengths of all fish in the codends and covers were recorded.

A replicated, controlled study in 2011 on fishing grounds in Mersin Bay, Mediterranean Sea, Turkey (34) found that a larger diamond codend mesh size in a trawl net improved size-selectivity and allowed a greater proportion of undersized and immature fish to escape compared to a smaller mesh size. The length at which fish had a 50% chance of escape was greater with a larger 50 mm mesh codend than a smaller 44 mm mesh codend for five of five species: goldband goatfish *Upeneus moluccensis* (large: 21 cm, small: 12 cm), red mullet *Mullus barbatus* (large: 12 cm, small: 8 cm), brushtooth lizardfish *Saurida undosquamis* (large: 28 cm, small: 23 cm), common pandora *Pagellus erythrinus* (large: 15 cm, small: 12 cm) and Randall's threadfin seabream *Nemipterus randalli* (large: 12 cm, small: 10 cm). The likelihood of being retained in the codend for undersized or immature fish was also lower with the larger mesh for four of four species (data reported as retention efficiencies - see paper for individual data). Data were collected from 41 trawl deployments (80–220 min) in Mersin Bay on a commercial fishing vessel in January–December 2011. Two codends were tested: 50 mm diamond mesh codend (21 hauls, 265 meshes circumference) and a 44 mm diamond mesh codend (20 hauls, 300 meshes circumference). Small mesh covers attached over each codend collected fish escaping through the meshes. All fish in the covers and codends were identified and their lengths measured.

A review in 2016 of 40 experimental fishing trials in the northeast Atlantic (35) found that trawl nets with larger codend mesh sizes, smaller codend circumferences and thicker netting twine had better size-selectivity for haddock *Melanogrammus aeglefinus*, and that the amount of smaller haddock caught in the gear was affected by the position of square mesh escape panels, when present. The length at which haddock had a 50% chance of escape increased by 3.4 cm for every 10 mm increase in codend mesh size, 1.3 cm for every decrease in codend circumference by 10 meshes and by 1.4 cm for every 1 mm decrease in twine thickness (data reported as statistical model results). In addition, escape of smaller haddock was higher with square mesh escape panels located closer to the codend. The study was a meta-analysis of data from 40 trials on the effects of changes to codend characteristics on the selectivity of haddock in the northeast Atlantic.

A replicated, controlled study in 2003 on bottom fishing grounds in the North Sea off Scotland, UK (36) found that a larger mesh size codend in a trawl net improved the size-selectivity of European plaice *Pleuronectes platessa* and haddock *Melanogrammus aeglefinus* compared to a smaller mesh codend. The size at which fish had a 50% chance of escape was greater with a larger 130 mm mesh codend, irrespective of twine thickness, than a smaller 120 mm mesh, for both plaice (large: 31–32 cm, small: 29–30 cm) and haddock (large: 34–39 cm, small: 32–36 cm). Data were collected in October 2003 from 30 deployments (40–210 min) of a standard commercial trawl net fitted with one of four different codends: a 130 mm diamond mesh codend (4.6 mm twine thickness, nine hauls), and three 120 mm diamond mesh codends of different twine thicknesses (4.1 mm, 4.6 mm and 5.1 mm, six to eight hauls each). Small mesh (17 mm) covers attached over each codend collected fish escaping through the meshes. All fish in the codends and covers were identified and weighed, and the lengths of haddock and plaice recorded. If catches were large, a subsample was measured.

A replicated, paired, controlled study in 2013 of a fished area of seabed in the Gulf of Maine, Atlantic Ocean, USA (37: same experimental set-up as 38) reported that larger mesh sizes in a bottom trawl codend improved the size-selectivity of non-commercially targeted saithe *Pollachius virens* compared to smaller mesh sizes. Data were not tested for statistical significance. The length at which saithe had a 50% chance of escape was 52.4 cm with the largest mesh size (165 mm), 45.6 cm with an intermediate mesh size (140 mm) and 34.8 cm with the smallest mesh size (114 mm). Data were collected in March-April 2013 from 21 trawl deployments (average 0.5 h duration) on a commercial bottom trawler using a trawl net with two diamond mesh codends (trouser trawl). One of three experimental codends with different diamond mesh sizes (165 mm – the minimum required mesh size, 140 mm, and 114 mm) was fished on one side, and a small diamond mesh (64 mm) codend on the other to sample the whole length range of fish. Each experimental codend was used for three days before being switched for a different mesh size (six to eight hauls of each pairing). Catch weights and the lengths of a random subsample of at least 100 saithe where possible from both codends were recorded each haul. Full gear details are provided in the original study.

A replicated, paired, controlled study in 2013 of a fished area of seabed in the Gulf of Maine, Atlantic Ocean, USA (38: same experimental set-up as 37) reported that larger mesh sizes in a bottom trawl codend improved the size-selectivity of commercially targeted Acadian redfish *Sebastes fasciatus* compared to smaller mesh sizes. Data were not tested for statistical significance. The length at which redfish had a 50% chance of escape was 33.6 cm with the largest mesh size (165 mm), 29.2 cm with an intermediate mesh size (140 mm) and 22.3 cm with the smallest mesh size (114 mm). Data were collected in March-April 2013 from 56 trawl deployments (average 0.5 h duration) on a commercial bottom trawler using a trawl net with two diamond mesh codends (trouser trawl). One of three experimental codends with different diamond mesh sizes (165 mm – the minimum required mesh size, 140 mm, and 114 mm) was fished on one side, and a small diamond mesh (64 mm) codend on the other to sample the whole length range of fish. Each experimental codend was used for three days before being switched for a different mesh size (16–22 hauls of each pairing). Catch weights and the lengths of a random subsample of at least 100 redfish where possible from both codends were recorded each haul. Full gear details are provided in the original study.

A replicated study in 2014–2015 of a fished area (bottom and surface) in the Arabian Sea, India (39) found that using a larger mesh size of drift gillnets improved the size-selectivity of silver pomfret *Pampus argenteus*, compared to a smaller mesh size. The selectivity of pomfret (measured as the optimum length - the length at which fish were retained by the gear at the highest frequency) was greater with a larger mesh size of 130 mm compared to a smaller 110 mm mesh size (large: 155 cm, small: 131 mm). In addition, the authors noted that a mesh size of 166 mm was the optimum for the release of pomfret at size at first maturity (199 mm). Fortnightly commercial gillnet data were collected between August 2014–April 2015 from vessels fishing out of the landing centre of Satpati, using either 130 mm or 110 mm mesh sizes (see original paper for gear and vessel specifications). The nets were deployed at the surface, in the water column or bottom drifted in depths from 35–50 m. Vessel numbers and fishing duration (soak times) were not reported.

A replicated study in 1997–2012 in two areas of seabed in the Skagerrak and Kattegat, Northern Europe (40) found that increasing the mesh size did not typically reduce the amount of undersized fish in bottom trawls or seine nets. For both trawl and seine nets, the ratio of undersized individuals/total number of individuals in catches was lower with larger mesh sizes (>109 mm) compared to smaller mesh sizes (90–109 mm) for one of six fish species, and similar between mesh sizes for five (data reported as statistical results). Data were collected in 1997–2012 by a discard sampling programme, from 460 and 285 commercial deployments by bottom trawlers (74 vessels) and seine netters (33 vessels), respectively. The mesh sizes used by each gear type were grouped into two categories: ≥110 mm and 90–109 mm. Regulatory changes during the sampling period included mandatory square mesh panels in trawl nets (2000 and 2011 – see original paper for specifications). After each deployment, the lengths of all fish were recorded.

A replicated, paired, controlled study in 2010 of an area of seabed in the southern North Sea, France (41) found that a trawl net made of larger mesh ('large mesh trawl') did not reduce the catches of unwanted small whiting *Merlangius merlangus*, compared to a trawl net of standard mesh size. Average whiting length was similar in catches between the large mesh trawl and a standard trawl (large: 27.0 cm, standard: 26.9 cm). Data were collected in January 2010 from 38 paired deployments by two 20–24 m commercial trawlers fishing parallel to each other: one rigged with a large mesh trawl net and the other a standard net (see paper for detailed specifications). Weights of commercial and non-commercial portions of the catch and total lengths of individual whiting were recorded. Random sub-sampling was done when catches were large.

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2.34 Use a different hook type

- **Twenty-five studies** examined the effect of using a different hook type on marine fish populations. Nine studies were in the Atlantic Ocean[1,2,6,7,14,16,17,20,22] (Portugal, South Africa, USA, Brazil, Portugal, Iceland), six studies were in Pacific Ocean[4,8,13,15,18,23] (New Zealand, Japan, Costa Rica, Hawaii, Fiji) and two studies were in the Mediterranean Sea[11,24] (Spain, Italy). One study was in each of the Barents Sea[3] (Norway), the Denmark Strait[5] (Greenland), the Coral Sea[9] (Australia) and the Strait of Gibraltar[12] (Spain/Morocco). Four studies were reviews[10,19,21,25] (worldwide, Atlantic and Pacific Oceans).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (10 STUDIES)

- **Survival (10 studies):** Four of seven replicated, controlled studies in the Atlantic Ocean[7,14,17], Pacific Ocean[4,8,15] and Coral Sea[9] and two of three worldwide systematic reviews[10,21,25], found that using different hook types in longline or recreational fisheries, including sizes[8,9,17], styles[7,8,10,14,15,21,25] and other modifications to hooks[4], reduced the incidence of fish hook injuries[4,9,15,21] (associated with higher post-release mortality), and reduced the capture mortality of some species of unwanted sharks and rays[14,21] and non-target billfish species[10], compared to conventional hooks or other hook types. The other four studies found that using a different hook type did not reduce the post-release mortality of young sea breams[17], or the capture mortality of sharks species[8,25] and non-target fish species[7], but did reduce the incidence of deep-hooking in some cases[7,17].

BEHAVIOUR (0 STUDIES)

OTHER (23 STUDIES)

- **Reduction of unwanted catch (20 studies):** Eight of 16 replicated studies (13 controlled, one randomized) in the Atlantic Ocean[1,6,7,14,16,20], Pacific Ocean[8,13,15,18,23], Barents Sea[3], Mediterranean Sea[11,24], Denmark Strait[5] and Coral Sea[9], found that using a different hook type, including different sizes[1,6,8,9,11], styles[5,6,7,8,13,14,15,16,18,20,23] and hook modifications[3,24], reduced the unwanted catch in longline and recreational hook fisheries of non-commercially targeted and targeted fish species[9], small non-target fish species[15], overall fish catch[11], overall discarded bony fish catch but not sharks and rays[20], undersized haddock[3], two of three unwanted fish species[24], non-target sharks and rays[23] and non-target rays and sailfish[16], compared to standard hooks or hooks of other types. Seven studies found that changing hook type did not reduce the unwanted catch of young or non-target fish species[1,7,18], unwanted sharks and rays[14], unwanted blue shark[8], unwanted roughhead grenadier[5] or non-target pelagic stingray and silky shark[13], compared to standard or other hook types. The other study[6] found that catch rates of young groupers, and non-target fish and shark species varied with hook design, and larger hooks caught fewer non-target fish species overall, but more undersized grouper and sharks compared to other hook types. Four global systematic reviews[10,19,21,25] found that hook style did not affect the unwanted catch of billfish species[10], sharks and rays[19,21] or sharks[25], compared to standard styles.
- **Improved size-selectivity of fishing gear (3 studies)**: Two of three replicated studies in the Atlantic Ocean[2,22] and Strait of Gibraltar[12], found that increasing hook sizes improved the size-selectivity (by increasing the average catch length) of hottentot[2] and black spot seabream[12] compared to smaller hook sizes. The other study[22] found that a different hook size improved size selectivity for two of five commercially targeted fish species and was also affected by bait size.

Background

In hook and line fishing, a fishing line is set with single or multiple baited hooks to attract fish. Whilst hook and line fishing is generally considered to be relatively selective, resulting in less unwanted catch than other gears, the type of hook used can influence the species and size of fish captured as well as the extent of hooking injury. Larger hooks, for example, may be effective at avoiding capture of smaller unwanted fish, whilst hooks of different shapes can also affect catch composition. Circle hooks, for example, are hooks on which the point is curved backwards in a circular shape, perpendicular to the main shaft, as opposed to a 'J' hook, which has the point parallel to the main shaft. Circle hooks may therefore reduce the incidence of hook swallowing in captured fish, minimising the severity of hooking injury and increasing survival in unwanted catch after release. Other modifications may include attaching inedible objects to hooks to act as deterrents to smaller fish or modifying the configuration of hooks on the mainline, such as changing the attachments.

Evidence for similar interventions affecting the capture of fish on hook and line is summarized under *'Fishing gear modification - Use a different bait type' and 'Modify longline configuration'*. See also, *'Deployment of fishing gear and mode of operation - Deploy fishing gear at selected depths to avoid unwanted species'*.

A replicated study in 1994–1995 in an area of sandy seabed in the Atlantic Ocean, off south-west Portugal (1) reported that using a larger hook did not typically reduce catches of small, unwanted fish, but overall catch rates were reduced compared to smaller hooks. Data were not tested for statistical significance. Overall, the average length of fish caught (34 fish species/groups and one octopus species) was larger for bigger hook sizes (largest hook: 30 cm; intermediate: 29 cm; smallest: 29 cm), but no increase in average size was found for most species, and all hooks caught a wide range of species (see original paper for species individual data). There were small increases however for four of the seven most abundant fish species in catches. Average catch weights were lowest for the largest hook size (largest hook: 77 kg, intermediate: 110 kg, smallest: 107 kg). A total of 45 longlines were deployed from March 1994 to March 1995 in water depths of 13–20 m. Hooks tested were a type commonly used by local small-scale fishers: round bent, flattened sea hooks (Mustad type) in three sizes: 11 (largest), 13 (intermediate, most widely used) and 15 (smallest) (see paper for hook dimensions). Individual longlines with 200–300 hooks of each size (39,900 total hooks) baited with razor clam were deployed for 2–4 h at a time. Catches were separated by hook type and species, weighed and fish total length measured.

A replicated study in 1985 in coastal waters in the Atlantic Ocean off Western Cape, South Africa (2) reported that changing hook type (size) resulted in different lengths of hottentot *Pachymetopon blochii* caught, and size range generally increased with larger hooks. No statistical tests were carried out. The average length of hottentot caught was 260 mm (range: 177–369 mm) with the widest hook used (18.3 mm), 258 mm (range: 160-385 mm) with a 14.4 mm hook, 251 mm (range: 160-351 mm) with a 10.7 mm wide hook, and 231 mm (range: 160-350 mm) with a 7.0 mm wide hook. Experimental line fishing for hottentot was done by 12 anglers over two days in September 1985 using four sizes of Mustad-type hooks (18.3, 14.4, 10.7 and 7.0 mm). Fishing gear was configured to match the traditional line fishery of the region and was undertaken from three dinghies in a marine reserve five nautical miles off the Western Cape. Equal periods of fishing were carried out with each hook size (31 hours of fishing effort/angler). All fish captured were counted and fish length measured at sea.

A replicated, controlled study in 1995–1996 of two pelagic areas in the Barents Sea, off north Norway (3) found that a modified hook design (plastic bodies attached) on pelagic longlines caught fewer undersized haddock *Melanogrammus aeglefinus*, but also reduced the total catch compared to standard hooks. In two of two trials of hooks with inedible plastic bodies attached, the proportions of haddock below legal size (44 cm) were lower than for hooks without plastic bodies (with: 12–31%, without: 15–34%), but overall haddock catch rates were also reduced (with: 43–68 fish/100 hooks, without: 52–77 fish/100 hooks). In one trial of unbaited hooks modified with nylon bristles, catch rates were lower compared to baited hooks without bristles (with: 3 fish/100 hooks, without: 74 fish/100 hooks), and so low that no further trials were done. Trials were carried out in July 1995 and June/July 1996 by two commercial longliners (see paper for full fishing specifications). Modified hooks had either inedible plastic bodies or coloured nylon bristles attached to the hook shank. Hooks were tested on longline fleets of lengths of 50 modified hooks alternated with 50 standard hooks. For trials with plastic bodies, a total of 4,845 modified hooks and 5,000 standard hooks were fished. In the nylon bristle trial, a total of 786 modified and 15,323 standard hooks were fished. Numbers and lengths of captured haddock were recorded.

A replicated, controlled study in 1999 in an area of seabed in the Hauraki Gulf, Pacific Ocean, off New Zealand (4) found that hooks modified with additional wire appendages reduced the amount of discarded snapper *Pagrus auratus* caught by the gut (associated with post-release mortality), compared to standard hooks in a longline fishery. Overall snapper catch rates were reduced with modified hooks relative to the standard hook (20 mm appendage: 22% less, 40 mm appendage: 33% less). Relative to catches with a standard hook, the relative likelihood of under-sized (<26 cm) snapper being captured by the gut was reduced with both types of modified hook (20 mm appendage: 78% less, 40 mm appendage: 96% less), and decreased with increasing length of hook appendage. Thirteen longline deployments were made from a fishing vessel in January and 12 in June 1999. Each longline had 1,350 hooks, with equal numbers of standard hooks, and two types of hooks modified with wire appendages (20- and 40-mm length). Lines were deployed for one hour. Arrow squid *Notodarus sloanii*, pilchard *Sardinops neopilchardus* and blue mackerel *Scomber australasicus* were used as bait. All catch was counted and fish length measured, and location of hook was recorded.

A replicated, controlled study in 1997 of deep water in the Denmark Strait off the east coast of Greenland (5) found that circle hooks (three types) did not reduce the catch of unwanted roughhead grenadier *Macrourus berglax* compared to standard hooks in a longline fishery. Overall, the percentage of hooks that caught unwanted grenadier was similar for both hook types (circle hooks: 13%, standard: 14%). However, between the three circle hook types, one caught fewer (11%) compared to the two other types (14–15%). In addition, catch rates of the target commercial species Greenland halibut *Reinhardtius hippoglossoides* were higher for the same one of three circular hooks compared to the standard hook (circle - blue: 435, standard 281 kg/1,000 hook), and the other two circle hooks were similar (344–368 kg/1,000 hook). Twenty-nine longlines with 1,560 hooks each were deployed from a fishing vessel between July–August 1997. Equal numbers of three types of circle hook and one type of standard hook baited with squid were tested (see original paper for hook specifications). Lines were recovered after 5–14 hours. All fish catch was counted and weighed.

A replicated, randomized study in 2003 in pelagic waters in Onslow Bay in the Atlantic Ocean, North Carolina, USA (6) found that catch rates of small groupers *Serranidae* spp., non-target fish species and sharks varied with hook design (circle or J), and larger hooks caught fewer non-target fish species overall, but more undersized grouper and sharks compared to other hook types, during commercial angling for grouper. Overall catch rates of 24 non-target fish species were lowest with the two largest hook types (12: 3 fish/day, 9: 4 fish/day) than the smallest two (7 and 5: 9 fish/day). Catch rates of sharks increased with increasing hook size and were lowest at the smallest hook size (1 shark/day) than the other hook sizes/types (2–3 sharks/day). Catches of small individuals (<50.8 cm) of six targeted grouper species were higher for the largest J-shaped hook (1 grouper/day) than any of the other three hook types (<1 fish/day), however the authors note that this may be due to the small sample sizewhile there were no differences for large groupers across all hook types (6–8 fish/day). In addition, the incidence of gut-hooked fish (higher odds of post-release mortality) was lower for non-target species with the two largest hooks compared to the smallest, and for groupers was lower with the circle hook compared to the three J-shaped hooks (data reported as statistical results). Twenty fishing trips were carried out 20–60 miles offshore from May–August 2003 (12–42 m depth). Four rods were used simultaneously, each with one of four randomly allocated hook sizes/types (5/0, 7/0, 9/0 J hooks or a 12/0 circle hook), baited with frozen fish. All fish landed were identified, counted and fish length measured, and the hook location recorded.

A replicated, controlled study in 2003–2004 in an area of pelagic water in the Atlantic Ocean and the Gulf of Mexico (7) found that changing conventional J-shaped hooks to circle hooks did not typically reduce the catches or mortality of non-target fish species in a longline fishery, but deep-hooking (associated with post-release mortality) was reduced. Across both surveys, catch rates of one of seven non-target fish species were lower on circle hooks than J hooks (see original paper for species individual data). The percentage mortality was lower on circle hooks than J hooks for only one of the 10 most commonly caught non-target species in both 2003 (circle: 7%, J hook: 30%) and 2004 (circle: 26%, J hook: 58%). However, the occurrence of deep-hooking was lower on circle hooks than J hooks for four of five species (data reported as statistical model results). Data were collected on a commercial pelagic longline vessel in the tuna *Thunnus* spp. and/or swordfish *Xiphias gladius* fisheries during two surveys: July-September 2003 (39 longline sets, using squid *Ilex* sp. as bait) and January-April 2004 (46 sets, mixed squid/mackerel *Scomber scombrus* bait). One circle hook type (size 16/0) and one J-shaped hook type (size 9/0) were set alternately on longline sections (30,600 hooks). See original paper for gear specifications.

A replicated, controlled study in 2005 in an area of coastal, pelagic water in the western North Pacific, off Japan (8) found that changing hook type and size to a circle hook from a standard hook did not reduce the unwanted catches, or capture mortality, of blue shark *Prionace glauca* in a longline fishery. Across both vessels, average blue shark catch rates were similar with larger hook sizes and different shape compared to the standard (largest: 36–94, intermediate: 38–95, standard: 41–82 sharks/1,000 hooks). Similarly, the proportion of dead individuals did not differ between hook types (data reported as statistical results). Data were collected on two research vessels from 52 fishing deployments between May–September 2005. A total of 900 hooks were used/longline deployment on one vessel and 960 hooks/longline for the other (all baited with Japanese common squid *Todarodes pacificus*). Blocks of 20 hooks of each of two test hook types (5.2 and 4.3 size circle hooks) and a standard Japanese hook type (3.8 size tuna hook) were fished in a repeating pattern on the longline. During hauling the species, number and condition of fish caught were recorded.

A replicated, controlled study in 2005 of four shallow coral reef areas in the Coral Sea, eastern Australia (9) found that changing hook size, but not hook type, reduced catch rates of non-target and target fish species, and there were reductions in hooking injuries with different hooks, compared to conventional J-type hooks used in a commercial line fishery. Across all fish species (five targeted and three non-targeted), catch rates were lower with large sized hooks (2.2 fish/0.5 h) than small (2.9 fish/0.5 h), and there were no differences between hook designs (offset circle: 2.5, non-offset circle: 2.8, J hook: 2.3 fish/0.5 h). Individually, catch rates of two species were lower using large hooks, and catch rate of one species was lower with both circle hook types than J-hooks (see original paper for species individual data). For all eight species combined, the percentage of fish caught with hooking injuries was reduced with non-offset circle hooks (non-offset circle: 3.7%, offset circle: 6.9%, J hook: 7.8%) and small hook sizes (small: 3.9%, large: 9.0%). Fishing trials took place on four research vessels (25 fishing sessions) during January–October 2005 within the Great Barrier Reef off the coast of Queensland (9–50 m depths). A total of six hooks were tested each session: size 4/0 and 8/0 J hooks, 5/0 and 8/0 offset (by 12°) circle hooks, and 5/0 and 8/0 non-offset circle hooks. Fishers were randomly assigned a hook-type at the start of a session and each hook was fished for 30 minutes in a sequential order, baited with pilchard. Captured fish were identified, counted and recorded as injured or uninjured.

A systematic review study in 2009 of hook effects on non-target billfish species *Istiophoridae* spp. in pelagic commercial and recreational fisheries in the Atlantic and Pacific Oceans (10) found that reductions in billfish mortality, but not catch rates, using circle hooks were found for four species compared to J hooks. No differences in catch rates (fish/1,000 hooks) between circle and J-shaped hooks were found in nine comparisons for the four species (white marlin *Tetrapturas albidus*, blue marlin *Makaira nigricans* and striped marlin *Tetrapturus audax*, and sailfish *Istiophorus platypterus*) in seven of seven studies. Three comparisons found reduced billfish mortality rates using circle hooks in three of seven studies, for: white marlin (circle: 0–48%, J-hook: 35–60%), blue marlin (circle: 53%, J-hook: 70%) and sailfish (circle: 33%, J-hook: 73%). However, seven other comparisons across five studies found no differences in mortality between hook types for each of the four billfish species. In addition, five of seven comparisons in five of six studies reported lower deep-hooking rates (associated with higher mortality) with circle hooks for white and striped marlin and sailfish, and two studies found no effect for white marlin. A quantitative review of hook effects (circle vs J hooks) on billfishes was conducted by searches of published and grey literature via library and electronic database records, as well as communications with agencies and individuals conducted by the author. Eleven studies reported species-specific hook data from commercial pelagic longline fisheries and recreational rod-and-reel fisheries.

A replicated study in 2004–2005 of rocky seabed in the Mediterranean Sea, off Majorca, Spain (11) found that larger hook sizes in a recreational fishery reduced overall catch numbers of fish, but maintained yields (weights), and size-selectivity was improved. Average catch rates by number were lowest at the largest hook size (5.7 fish/angler/30 min) compared to the smallest (8.6 fish/angler/30 min), and the three intermediate sizes were similar to each other (6.1–7.5 fish/angler/30 min). However, there were no differences in the overall yield (average catch weight) between all five hook sizes (212–240 g/angler/30 min). The length at 50% selectivity of four common fish species occurring in similar size frequencies differed between hook types and, although the size of the differences varied between species, increased with increasing hook size (largest: 9.2–14.6 cm, smallest: 7–10.1 cm). From March 2004 to August 2005, a total of 33 angling trips were conducted at 10–35 m depths. Angling trips were 30 min long and were fished using J-hooks of one of five hook sizes, from size H4 (the largest) large to size H8 (the smallest, see original paper for hook dimensions). Fish captured were counted and fish length measured.

A replicated study in 2000–2005 on rocky seabed in the Strait of Gibraltar, Spain (12) found that larger hooks improved the size-selectivity of black spot seabream *Pagellus bogaraveo* compared to smaller hooks in a longline fishery, but depended on size structure of the population being fished. Across both trials, the average length of seabream caught, and the subsequent estimates of size-selectivity, differed between all four hook sizes (except in the second trial for two hooks of similar dimensions, sizes 9.5 and 10), and increased with increasing hook size (data reported as graphical analyses). In addition, seabream length frequencies and selectivity estimates differed between trials as the result of differences in the size structures of the populations encountered. Two experimental fishing trials using four sizes of circular hook were done on a commercial vessel in the Strait of Gibraltar from November 2000 to July 2005. Trial one tested three hook sizes (9, 10, 11, largest to smallest) on 50 longline sets (3,500 hooks of each size). Trial two tested a size 9.5 hook with sizes 9 and 10 during 106 sets (7,420 hooks each size). See original paper for hook dimensions. All hooks were baited with sardine *Sardina pilchardus* and fishing was done at depths up to 850 m over rocky seabed.

A replicated, controlled study in 2004–2006 in pelagic waters in the Gulf of Papagayo, Pacific Ocean, Costa Rica (13) found that using a different circle hook type (offset) in a longline fishery targeting dolphinfish *Coryphaena hippurus* did not reduce the incidental capture of pelagic stingray *Pteroplatytrygon violacea* or silky shark *Carcharinus falciformis*, compared to conventional non-offset circle hooks. Incidental catch was similar with offset and non-offset hooks for stingray (6.1 vs 4.7 ind/line) and silky shark (1.8 vs 2.5 ind/line). Eleven species of bony fish were also caught incidentally, for which catches were higher on offset hooks compared to non-offset hooks for seven species, lower for two and similar for two (see original paper for species individual data, not tested statistically). Data were collected from fishing trips between November and March 2004–2006, deploying longlines with offset (by 10°) and non-offset circle hook types (size 14/0) set alternately along 7 m lines attached to the main monofilament fishing line. All trips used Humboldt squid *Dosidcus gigas* as bait to target dolphinfish. Lines were deployed in the morning and soaked for 12 hours. All species caught/hook type were recorded. Data from 33,876 hooks across six trips were included in the analysis.

A replicated, controlled study in 2004–2005 of one area of seabed and one mid-water area in the Atlantic Ocean, off Brazil (14) found that using a circle hook type instead of a conventional J-type hook in a longline finfish fishery did not reduce the capture of unwanted sharks and rays (elasmobranchs), but did reduce the capture mortality of some species. For pelagic longlines, incidental catch rates were similar between the circle and conventional J hook for six of 10 shark species (circle: 0.3–1.8, J hook: 0.3–2.1 catch/unit effort), however, they were higher for four (circle: 2.3–6.4, J hook: 0.8–2.6 catch/unit effort). Total fishing mortality rates of three species were lower on circle hooks (22–27%) than J hooks (67–80%) and, although survival was typically higher on circle hooks for the other seven species, they were not statistically different (0–100% on both hook types). For demersal longlines, there were also no differences in catch rates between hook types for eight shark and ray species (circle: 0.2–1.4, J hook: 0.0–1.3 ind/1,000 hooks), and fishing mortality of two shark species was lower on circle hooks (0–23%) than J hooks (50–74%). See original paper for species individual data. Between August 2004 and April 2007 two hook experiments were carried out with pelagic and bottom set longlines. A total of 224 pelagic longline sets (7,800 hooks, moray-eel *Gymnothorax* spp. bait) were deployed off Recife (8–14 m depth, 1–3 km from the coast) with alternate sets of circle hooks (size 18/0, 0° offset) and conventional J hooks (size 9/0, 10° offset). Twelve demersal longline sets (650 hooks, skipjack tuna *Katsuwonus pelamis* bait) were deployed off Natal at 40–70 m depths. Hook types (circle and J hooks as before) were alternated in equal numbers for each set.

A replicated, controlled study in 2005–2006 in an area of pelagic water in the Pacific Ocean around Hawaii, USA (15) found that circle hooks typically caught fewer and larger unwanted non-target fish species compared to two conventional hook types used in the longline fishery for bigeye tuna *Thunnus obesus*, and that fish condition (as a proxy for post-release survival) was higher for some unwanted species. Circle hooks reduced catch rates of 14 of 14 and eight of 14 unwanted species, compared to conventional tuna and J hooks respectively, as well as two of three and three of three non-target but commercially valuable (incidental) species. Circle hooks caught similar numbers of bigeye and incidental yellowfin tuna *Thunnus albacares* as tuna hooks and similar numbers of bigeye tuna as J hooks (data reported as statistical model results). Fish length varied between hook types for four of seven unwanted species, and two incidental species. Of the unwanted species that showed differences, two species were largest with circle hooks and two with J hooks. Length of target bigeye tuna and incidental yellowfin tuna were similar across hook types (data reported as statistical model results). The condition (as a proxy for survival) of fish captured using circle hooks was higher for three and five unwanted species compared to tuna and J hooks respectively (data reported as statistical model results). Data were collected between June 2005–February 2006 on 16 tuna longline vessels. Vessels alternated a circle hook type (size 18/0) with one of two existing hook types (Japanese tuna hook or J hook, size 9/0) throughout the longline gear. Observers monitored 1,393 sets (1,182 circle vs tuna hooks, 211 circle hooks vs J hooks). See original paper for gear specifications. All fish caught were identified, and fish length and condition recorded.

A replicated, controlled study in 2006–2007 in an area of pelagic water in the Atlantic Ocean, off Brazil (16) found that circle hooks caught fewer unwanted rays *Myliobatiformes* and sailfish *Istiophorus platypterus* compared to J hooks, and overall similar amounts of other target and non-target fish groups. Overall, circle hooks caught fewer rays (two species, mainly pelagic stingray *Pteroplatytrygon violacea*) than J hooks (circle: 21, J hook: 161). Catches of unwanted sailfish were also lower on circle hooks (2) than J hooks (10). Overall catches of three other species groups (billfish *Istiophoridae*, other bony fish and sharks) and total catch composition were similar for each hook type (data reported as statistical model results). The occurrence of deep-hooking injuries (associated with higher post-release mortality) was lower on circle hooks than J hooks for all species groups (data reported as graphical analysis). In addition, target catches of tunas *Thunnus* spp. were higher on circle (29/1,000 hooks) than J hooks (23/1,000 hooks), but swordfish *Xiphias gladius* catches were similar. Data were collected during six pelagic longline trips using three vessels in August 2006 and January 2007. A total of 81 longline sets were fished (50,170 hooks) with circle hooks (size 18/0, 0° offset) alternated equally with J hooks (size 9/0, 10° offset) baited with squid *Illex* sp.

A replicated, controlled study in 2009 at a fish farm reservoir in the Atlantic Ocean, off southern Portugal (17) found that changing hook size did not affect the short-term post-release mortality of immature individuals of three sea bream *Sparidae* species, but survival of fish that were deep-hooked with an intermediate sized hook was reduced. Overall post-release mortality rate for the three species combined was low (6%) and ranged from 0% and 3% for the two-banded *Diplodus vulgaris* and black *Spondyliosoma cantharus* sea breams, respectively, to 12% for gilt-head sea bream *Sparus aurata*. Hook size alone did not affect mortality rates. However, deep-hooked fish were 2.6 times more likely to die than shallow-hooked fish, and fish hooked with the intermediate sized hook were deeply hooked more frequently than the smaller and larger hook sizes (data reported as statistical results). A total of 384 fish of the three bream species were captured by six anglers in October 2009 from a fish farm reservoir in the Ria Formosa. Three typically used hook sizes were tested, baited with ragworm *Hediste diversicolor* (7.5, 7.9 and 10.6 mm barb widths, see original paper for other dimensions). Two randomly selected hook sizes were trialled/fisher. After capture, fish total length and hooking location were recorded by species and fish were tagged. Tagged fish were placed into 1 m^3 sea cages and the number of dead fish recorded after 2–3 h.

A replicated, controlled study in 1994–2010 in an area of pelagic water in the Pacific Ocean off Hawaii, USA (18) found that using circle hooks in a longline tuna *Thunnus* spp. fishery did not typically reduce the amount of unwanted catch of other fish species compared to conventional J-shaped or tuna hooks. The data were reported as statistical results (response to hook design of standardized catch rates). Catch rates of unwanted shortbill spearfish *Tetrapturus angustirostris* and striped marlin *Tetrapturus audax* were lower on sets using the wider circle hooks than sets with the narrower J-style and tuna hooks, but catch rates of unwanted blue shark *Prionace glauca* and oceanic white tip shark *Carcharhinus longimanus* and bigeye thresher shark were higher. Swordfish *Xiphias gladius* and bigeye thresher shark *Alopias superciliosus* standardised catches were not affected by hook type. In addition, target catches of tuna species *Thunnus obesus* were higher on sets with circle hooks than J or tuna hooks. Observer data were analysed from the Hawaii longline tuna fishery, collected between March 1994–July 2010. Catch data from nearly 72 million hooks in 34,613 sets from 2,767 trips were included. The predominant hook types used were various designs and sizes of circle hook (6 main types), J hook (2 main types) and tuna hooks (4 main types) See original paper for hook specifications.

A systematic review in 2015 of 44 studies assessing the reduction of unwanted catch of sharks and rays (*Elasmobranchii*) in longline fisheries worldwide (19) found that using circle hooks or appendage hooks (circle hooks with an additional wire arm to increase its width) did not reduce the overall amount of unwanted sharks and rays caught compared to traditional J hooks, but did catch fewer of one of three individual species. Overall, the catch percentages of sharks and rays caught on circle and appendage hooks were similar to J hooks but catches of pelagic stingray *Pteroplatytrygon violacea* were reduced by almost 75% on circle hooks. Blue shark *Prionace glauca* and Galapagos shark *Carcharinus galapagensis* catches were similar between all hook types (data reported as graphical analysis). The systematic review summarized the effects of various actions to reduce unwanted catch (see original paper for search methods) from 27 publications yielding 44 studies reporting shark and ray catch data. A total of 23 and 17 studies reported effects of using circle hooks and appendage hooks, respectively, relative to control hooks.

A replicated, controlled study in 2008–2012 in a wide area of pelagic water spanning the Southern Atlantic Ocean (20) found that using two circle hook types instead of a traditional J hook in a commercial longline fishery targeting swordfish *Xiphias gladius*, reduced the overall discarded catch of bony fish, but not sharks and rays (*Elasmobranchii*), and the effects varied between species. Average catch rates of total discarded bony fish (five species/groups) were lower on circle hooks than J hooks (circle: 0.8–0.9, J hook: 1.8 ind/1,000 hooks), but this varied between individual species. Catch rates of all shark and ray discards (nine species/groups) did not differ between hook types (circle: 2.3–2.6, J hook: 2.3 ind/1,000 hooks), but there were also differences for individual species (see original paper for species individual data). Data were collected from 310 experimental longline sets, deployed from October 2008 to February 2012. Three different hook types were tested: two circle hooks of identical dimensions, but one with no offset angle and one offset by 10°, and one existing J-style hook used by the Portuguese swordfish pelagic longline fleet (see original paper for gear specifications). A total of 446,400 hooks were fished, baited with mackerel *Scomber* spp. and squid *Illex* spp., with hook types alternated in groups of 80 hooks.

A systematic review in 2016 of 40 studies assessing actions to reduce unwanted catch in pelagic longline fisheries worldwide (21) found that using circle hooks instead of J-style hooks did not typically reduce the number of unwanted sharks and rays (*Elasmobranchii*) caught, but they did increase survival rate and reduce the incidence of deep-hooking. All data were reported as graphical analyses – see original paper. Catch rates were higher on circle hooks than J hooks for four of five species and lower for one species Survival rates at gear retrieval were higher on circle hooks than J hooks for three of three species. Using wider circle hooks rather than narrow J hooks increased catch rates of five of nine and reduced catch rates of four of nine species, whilst survival rates at gear retrieval were higher for five of six species and lower for one of six. The proportion of deep-hooked individuals (leading to higher fishing mortality) was lower on wider circle hooks than narrow J hooks for six of six species. In addition, wider hooks (of all designs) increased catch rates in one case and decreased them in another, compared to narrow hooks, and increased survival at gear retrieval. Wider circle hooks baited with fish bait caught more of three of four species and fewer of one of four species, compared to narrow hooks (of all designs). All data were reported as ratios of the number of findings with a significant increase or decrease. A meta-analysis was done of 40 studies in global locations on the effects of different hook and bait types on unwanted shark/ray catch rates, survival and deep-hooking injury, in pelagic longline fisheries.

A replicated study in 2008–2009 in six areas of deep water in the North Atlantic Ocean, off Iceland (22) found that changing the hook size on longlines improved size selectivity for only two of five commercially targeted fish species, but reduced catch numbers of all species, and was also affected by bait size. Across both areas, hook size affected fish size selectivity only for wolffish *Anarhichas lupus* and cod *Gadus morhua* in the northern area, but not haddock *Melanogrammus aeglefinus,* tusk *Brosme brosme* or ling *Molva molva* (data reported as statistical results). The average length of wolffish caught increased by 1.3 cm for each increase in hook size, irrespective of bait size. However, for cod in the northern area, hook size improved size selectivity only when the small bait size was used, and average length increased by 1.4 cm with every increase in hook size. In addition, catch numbers decreased with increasing hook size for all species (data reported graphically). Six fishing trials were conducted on commercial longliners between November 2008 and December 2009 (five trials north of Iceland, one trial in the south) at depths of 50–140 m. Five hook sizes (EZ-Baiter hooks, sizes 10–14) and two sizes (10 and 30g) of Pacific saury *Cololabis saira* bait were tested (see original paper for dimensions). The two bait types were alternated in 100-hook blocks, each divided into five 20-hook blocks rigged with one of the five hook sizes. A total of 4,800 hooks were set each trip (except one trip of 2,400 hooks). Lines were hauled after one hour and fish species, number and length recorded.

A replicated, controlled study in 2011–2014 in an area of pelagic water in the South Pacific Ocean around Fiji (23) found that using circle hooks in a longline fishery targeting mainly tunas (*Scombridae*) and swordfish (*Xiphiidae*) resulted in fewer incidental captures of sharks (*Selachii*) and rays (*Batoidea*), compared to conventional J-shaped hooks alone or a combination of J and circle hooks. Using circle hooks alone caught fewer sharks and rays than using J-shaped hooks or a combination of J and circle hooks, and fishing in July–December resulted in fewer shark and ray captures, compared to fishing in January–March (data reported as statistical model results and odds ratios). In addition, using larger size bait and shorter (<17 m) distances between secondary lines attached to the mainline reduced the incidental capture of rays (data reported as statistical model results and odds ratios). Data from 2,367 gear deployments were obtained from the Fiji Observer Programme for the Fiji longline fishery covering the period January 2011 to

December 2014. Data were analysed to assess the effect of different factors on incidental capture of sharks and rays. These included hook type (J-shaped and circle hooks), bait sizes (large and small), distances between the branching lines on the mainline, years and season.

A replicated, controlled study in 2009–2013 in an area of pelagic water in the Mediterranean Sea, off Sicily, Italy (24) found that hooks attached to the fishing line with rings ('ringed' hooks) caught fewer of two of three unwanted species in a longline swordfish *Xiphias gladius* fishery, compared to hooks attached directly to the line. Ringed hooks caught fewer unwanted sunfish *Mola mola* (0.04 ind/1,000 hooks) and blue shark *Prionace glauca* (0.04 ind/1,000 hooks) compared to non-ringed hooks (sunfish: 0.08, blue shark: 0.19 ind/1,000 hooks). However, numbers of unwanted pelagic stingray *Pteroplatytrygon violacea* were higher on ringed hooks than non-ringed hook (ringed: 0.71, non-ringed: 0.63 ind/1,000 hooks). Target swordfish and bluefin tuna *Thunnus thynnus* catches were higher on ringed hooks than non-ringed hooks (swordfish: 8.47 vs 6.65, tuna: 0.71 vs 0.47 ind/1,000 hooks). Catches of targeted little tunny *Euthynnus alletteratus* were similar between hook types (both 0.04 ind/1,000 hooks) but target dolphinfish *Coryphaena hippurus* catches were lower on ringed hooks (ringed: 0.00, non-ringed: 0.04 ind/1,000 hooks). Fishing trials took place in July–September in 2009–2013 using ringed or non-ringed circle hooks (size 16/0). Hooks were 5 cm long and either attached to the branchline with a ring or directly to the line, with each type set alternately along the mainline. Sixty-five sets of gear were fished from six vessels, totalling 50,800 hooks.

A systematic review in 2018 of 42 studies of the effects of hook type in pelagic longline fisheries worldwide (Atlantic and Pacific Oceans) (25) found that using circle hooks instead of conventional J-style hooks did not reduce catch rates of unwanted sharks (*Selachii*), and did not typically reduce the mortality of most sharks upon gear retrieval. Data were reported as statistical results – see original paper. There was no difference between hook types in catch rates of seven of 13 species, whilst catch rates of six of 13 unwanted shark species were higher on circle hooks than on J hooks. Mortality upon gear retrieval was lower for three of ten shark species on circle hooks than J hooks, and similar for seven species. Catches of target tuna *Thunnus* spp., billfishes *Istiophoridae* and swordfish *Xiphiidae* were higher on circle hooks than J hooks in five of 13 cases and lower in two cases. The systematic review summarized the effects of using circle hooks in longline fisheries compared to conventional J hooks on catch rates and at-vessel mortality during gear retrieval from 42 studies.

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2.35 Use a different bait type

- **Eleven studies** examined the effects of using different bait on marine fish populations. Two studies were global systematic reviews[8,9]. Three studies were in the North Atlantic Ocean[5,6,10] (USA, Iceland).Two studies were in the South Pacific Ocean[3,11] (New Zealand). One study was in each of the Norwegian/Barents Seas[1] (Norway), the Barents Sea[2] (Norway), the Denmark Strait[4] (Greenland) and the Mediterranean Sea[7].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** One replicated study in the South Pacific Ocean[3] and one global systematic review[9] found that using different bait species did not reduce hooking injuries (associated with higher post-release mortality) of undersized snapper[3] or sharks and rays[9], and did not increase survival of sharks and rays on gear retrieval[9].

BEHAVIOUR (0 STUDIES)

OTHER (10 STUDIES)

- **Reduction of unwanted catch (10 studies):** Six of eight replicated studies (three controlled and one randomized) in the Norwegian/Barents Seas[1], Barents Sea[2], Denmark Strait[4], North Atlantic Ocean[5,6,10], Mediterranean Sea[7] and the South Pacific Ocean[11], found that using a different bait type (including size, species and manufacture method) reduced the unwanted catches of undersized haddock[1,2,] (although in one case in only two of six comparisons[2]), Atlantic cod[5,6] and other unwanted or non-target fish catch[4,10], but unwanted catches of torsk and ling were similar[1], compared to standard or other bait types. Two other studies[7,11] found no reduction in unwanted catches of pelagic stingray[7] and overall unwanted fish[11] with different bait types. Two systematic global reviews[8,9] found that using different bait types did not affect the number of unwanted sharks and rays caught.
- **Improved size-selectivity of fishing gear (1 study):** One replicated study in the Denmark Strait[4] found that using a different bait species increased the size-selectivity of commercially targeted Greenland halibut.

Background

Some static (non-mobile) fishing gears typically attract fish using bait, as opposed to mobile gears that move through the water column to capture fish, or other static gears that passively allow fish to swim into the gear. The use of bait exploits a species' natural feeding behaviour to increase the chances of capture, for example by encouraging entry into traps where exit is limited, or by taking bait from hook and line and becoming caught on the hook. Static gear fishing is highly dependent on the feeding ecology of the target species (Løkkeborg *et al*. 2014) and changing the type or size of bait may influence fishing efficiency and the amount of unwanted species or sizes caught. For example, the size of prey consumed is limited by fish gape size (Mittelbach & Persson 1998), and using larger bait may therefore limit the capture of smaller fish, whilst one type of bait may be less attractive to non-target and unwanted species over another and reduce their capture.

Evidence for similar interventions affecting the capture of fish on hook and line is summarized under *'Fishing gear modification - Use a different hook type'* and *'Modify longline configuration'*. See also, *'Deployment of fishing gear and mode of operation - Deploy fishing gear at selected depths to avoid unwanted species'*.

Løkkeborg S., Siikavuopio S.I., Humborstad O.B., Utne-Palm A.C. & Ferter K. (2014) Towards more efficient longline fisheries: fish feeding behaviour, bait characteristics and development of alternative baits. *Reviews in Fish Biology and Fisheries,* 24, 985–1003.

Mittelbach G.G. & Persson L. (1998) The ontogeny of piscivory and its ecological consequences. *Canadian Journal of Fisheries and Aquatic Sciences*, 55, 1454–1465.

A replicated, controlled study in 1990–1991 in two pelagic areas in the Norwegian/Barents Seas, off Norway (1) found that bait on pelagic longlines that had been made to appear larger caught fewer small and undersized haddock *Melanogrammus aeglefinus* than bait of a standard, smaller size, but catches were similar for torsk *Brosme brosme* and ling *Molva molva*. When bait appeared larger, fewer small and undersized (<46 cm) haddock were caught (26 fish) than with standard sized bait (45 fish). However, catches of larger, legal sized (>46 cm) haddock were similar for each bait type (large: 67, standard: 74 fish). Total catch of torsk was similar between bait types, across all sizes (large: 173, standard: 160 fish) (no ling data presented.) In addition, the mean size of fish caught on experimental and standard baits was similar for torsk (54 vs 54 cm) and ling (91 vs 95 cm). Trials were carried out in November 1990 (western Norway, 120–370 m depth), and in July 1991 (northern Norway, 373–415 m depth). Experimental bait was made from a piece of plastic attached to the shank of a circle hook around which the bait was wrapped, giving it a larger appearance. Hooks were baited with mackerel (Scombridae) in western Norway, and mackerel and squid (Cephalopoda) in northern Norway. Hooks were left for 4–14 h in western Norway and 11–12 h in northern Norway. Detailed gear specifications are given in the original paper.

A replicated, controlled study in 1996 of two coastal pelagic areas in the Barents Sea, off north Norway (2) found that longline catches of undersized haddock *Melanogrammus aeglefinus* were lower in two of six comparisons of four different bait types with normal bait. In one trial, the proportion of haddock below the legal size (44 cm) was lower on restructured sandeel *Ammodytes* spp. bait (5%) and large mackerel *Scomber scombrus* bait (9%) compared to normal mackerel bait (16%), but similar on restructured mackerel bait (17%) or large restructured mackerel bait (14%). Overall catch rates were similar on all five bait types (51–76 fish/100 hooks). In another trial, restructured baits of sandeel and mackerel caught similar proportions of haddock below the legal size (44 cm) as normal mackerel bait (restructured: 17–19%, normal: 18%) and catch rates were also similar (restructured: 57–76 fish/100 hooks, normal: 74 fish/100 hooks). Two trials were carried out in June/July 1996 by two commercial longliners fishing in two areas using different hooks/rigging configurations (see paper for specifications). Four bait types and sizes (twice the normal size) were tested against a standard bait of 2 cm-thick slices of mackerel. Restructured baits were based on minced fish and algal binding agent. Baits were tested on longline fleets consisting of groups of 50 hooks with test baits (400–4,566 hooks) alternated with groups of 50 hooks with standard baits (7,250–15,323 hooks). Numbers and lengths of haddock captured were recorded.

A replicated study in 1999 in a coastal gulf in the South Pacific Ocean off New Zealand (3) found that using different types of bait in a longline fishery did not alter the incidence of hooking injury (related to higher post-release mortality) in unwanted undersized snapper *Pagrus auratus*. Proportional catches of undersized snapper hooked by the lip were similar for each bait type (squid *Notodarus sloanii*: 0.02, pilchard *Sardinops neopilchardus*: 0.02, mackerel *Scomber australasicus*: 0.02), and undersized snapper caught by the gut (squid: 0.016, pilchard: 0.011, mackerel: 0.015). In addition, the proportion of all sizes of snapper hooked by the gut was similar (squid: 0.2, pilchard: 0.1, mackerel: 0.1). Data were collected onboard a fishing vessel in the Hauraki Gulf in 1999, from 13 (January) and 12 (June) longline deployments. Each longline had 1,350 hooks, baited with equal numbers of the three bait types. Lines were left in the sea for one hour. Arrow squid, pilchard and blue mackerel were used as bait. All catch was counted and measured. Location of hook (lip or gut) was recorded.

A replicated study in 1997 in an area of seabed in the Denmark Strait off the east coast of Greenland (4) found that baiting hooks in a longline fishery with grenadier (Macrouridae) reduced the catch of unwanted (non-target) fish, and increased the size-selectivity of the target Greenland halibut *Reinhardtius hippoglossoides*, compared to squid bait (Cephalopoda). The proportion of the total number of hooks with unwanted non-target fish (consisting mostly of roughhead grenadier *Macrourus berglax*) on them was lower for grenadier bait (1%) than for squid bait (21%). For the target halibut, catch rates were 34% more using grenadier bait. However, the average size of halibut caught were larger (grenadier: 82 cm, squid: 72 cm). Data were collected from deployments of five longline sets (750–1,080 m depth, 5–14 h), by a fishing vessel between July-August 1997. Each set had 1,560 standard hooks, baited alternately with squid or grenadier (species not reported). All halibut and unwanted fish caught were counted, and their lengths recorded.

A replicated, controlled study in 2003–2005 in an area of seabed on the Georges Bank in the North Atlantic Ocean, USA (5) found that using a fabricated bait instead of a natural bait reduced the amount of unwanted cod *Gadus morhua* in a bottom longline fishery for haddock *Melanogrammus aeglefinus*. Overall, the average weight of cod/haddock caught was lowest with the fabricated bait (<0.01 kg cod/kg haddock); and herring bait caught less cod (0.01–0.03 kg cod/kg haddock) than squid bait (0.02–0.07 kg cod/kg haddock). Data were obtained from records of 147 longline trips (621 deployments, 78 or 92 m depth) conducted by commercial fishers from October 2003–June 2005, under special permits to fish in an area closed to groundfish fishing since 1994. Three bait types were tested: three fabricated baits combined for analysis ('Norbait' based on herring, mackerel or both), squid and herring (species not reported).

A replicated, randomized study in 2007 of an area in the Gulf of Maine, USA (6) found that using a manufactured instead of a natural bait reduced the amount of unwanted Atlantic cod *Gadus morhua* caught in a longline fishery for haddock *Melanogrammus aeglefinus*. Total catches of cod were lower with manufactured bait (172 kg) than with natural herring *Clupeus harengus* (461 kg) or clams *Mercenaria mercenaria* (640 kg). The amount of unwanted cod/targeted haddock was also lower using manufactured bait (0.4) than herring (1.1) or clams (0.8). Legal-sized haddock catch was not statistically different between the manufactured bait (309 kg), herring (257 kg) or clam baits (640 kg). Catches of seven other non-target fish species were mainly caught with herring bait rather than the manufactured bait or clams (not statistically tested). In April-May 2007, eight experimental fishing trips were carried out in Massachusetts Bay. During each trip, a longline set was deployed in three areas, each with six sections (250 hooks). One of three bait types was alternated every two sections: commercially manufactured bait ('Norbait', mainly Atlantic mackerel *Scomber scombrus*), herring and clams. Bait order was randomized, and each string was set at 60 m. Hooks were 11/0 circle hooks 41 mm long and 2 mm in diameter. See original study for full details of the bait used.

A replicated study in 2005–2007 in pelagic waters in the Mediterranean Sea, Italy (7) found that changing the size of the bait on pelagic longlines did not reduce the unwanted catches of pelagic stingray *Pteroplatytrygon violacea*. Neither the size of bait size (small or large), or the absence of light attractors, had a significant influence on the number of stingrays captured (data reported as statistical results). However, average catch rates were lowest with circle hooks (1 stingray/1,000 hooks) compared to J shaped hooks, and larger J hooks had lower catches than smaller J hooks (large: 3–6, small: 6–8 stingray/1,000 hooks). A total of 97 experimental fishing sets (86,116 hooks) were done between June-October from 2005–2007 in the Strait of Sicily, on nine commercial vessels targeting mainly swordfish *Xiphias gladius*. Small baits were round sardinella *Sardinella aurita* and horse mackerel *Trachurus trachurus* (26 sets), and the large bait was mackerel (*Scombridae*) (71 sets). Hooks were J shaped (two small, one large) alternated with circle hooks (one size). Light attractors (battery operated and chemical light sticks) were deployed on 72 sets.

A systematic review in 2015 of two relevant studies from 44 that assessed a range of ways to reduce unwanted catch in longline fisheries in global pelagic waters (8) found that changing bait colour (dyeing it blue) did not reduce the unwanted catches of sharks and rays (*Chondrichthyes*) compared to traditional bait. Numbers of sharks and rays caught on bait that had been dyed blue were similar to those caught on traditional, non-dyed bait (data reported as graphical analysis). Three global databases were searched, and publications identified that reported the numbers of sharks and rays caught in fishing gears with and without devices to reduce unwanted catch (‘bycatch reduction devices). A meta-analysis was carried out on 44 studies, two of which two contained data on the effects of using different bait types.

A systematic review in 2016 of 41 studies of pelagic longline fisheries worldwide (9) found that changing bait type (using fish instead of squid), did not typically reduce the number of unwanted sharks and rays (*Elasmobranchii*) caught, or the incidence of deep-hooking injury associated with higher mortality, and did not increase survival at gear retrieval. Data were reported as graphical analyses (see review). When using fish instead of squid for bait, catch rates of sharks and rays were higher for seven of nine unwanted elasmobranch species, and lower for two species. Fish bait increased the incidence of deep-hooking injury in one of one unwanted species compared to squid bait. In addition, wider circle hooks baited with fish bait caught more of three of four species and fewer of one of four species, compared to narrow hooks (of all designs). The study performed a meta-analysis of 41 studies globally on the effects of different hook and bait types in pelagic longline fisheries on unwanted elasmobranch catch rates, survival and deep-hooking injury (see original paper for full search methods).

A replicated study in 2008–2009 in six areas of deep water in the North Atlantic Ocean, off Iceland (10) found that increasing the bait size reduced the capture of unwanted small fish compared to using a smaller bait size. The average length of hooked fish was greater with larger bait size than smaller bait for: cod *Gadus morhua* (large: 55–72 cm, small: 46–70), haddock *Melanogrammus aeglefinus* (large: 47–53 cm, small: 45–52,), tusk *Brosme brosme* (large: 47 cm, small: 43 cm), ling *Molva molva* (large: 65 cm, small: 63 cm) and wolffish *Anarhichas lupus* (large: 48–64 cm, small: 45 cm). Six fishing trials were conducted from commercial longliners between November 2008 and December 2009 (five trials off the northwest coast of Iceland, one trial off the southwest) at depths of 50–140 m. Large (30 g) and small (10 g) sizes of bait made of Pacific saury *Cololabis saira* were alternated every 100 hooks (up to 4,800 hooks/set) and gear fished for one hour. Hooked fish were recorded and their lengths measured.

A replicated study in 2014 of two areas of seabed in the South Pacific Ocean, New Zealand (11) found that using different bait types in crustacean traps did not reduce the catches of unwanted fish. In the first trial testing mackerel *Scomber australasicus* and squid *Nototodarus sloanii* baits, there was no significant difference in the amount of unwanted fish catch between baits (mackerel: 0.6 fish/trap, 0.2 fish/trap). In the second trial, unwanted fish catch again was similar using barracouta *Thyrsites atun* bait (3.7

fish/trap) compared to squid bait (2.2 fish/trap). Bait species were tested in two trials on grounds fished for New Zealand scampi *Metanephrops challengeri*. In November/December 2014, a total of 140 traps baited with squid and 139 baited with mackerel were deployed at Chatham Rise. In April 2015 at Cape Palliser, 46 traps baited with squid and 45 with barracoota were deployed. Four types of traps were used, equal numbers baited with each bait species. All traps were deployed on the seabed and left for 18 hours before retrieval. All unwanted catch was identified and counted.

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(3) Willis T.J. & Millar R.B. (2001) Modified hooks reduce incidental mortality of snapper (*Pagrus auratus: Sparidae*) in the New Zealand commercial longline fishery. *ICES Journal of Marine Science*, 58, 830-841.

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(11) Major R.N., Taylor D.I., Connor S. & Connor G. (2017) Factors affecting bycatch in a developing New Zealand scampi potting fishery. *Fisheries Research*, 186, 55–64.

2.36 Modify longline configuration

- **Four studies** examined the effects of modifying longline configuration on marine fish populations. One study was in each of the Norwegian Sea[1] (Norway) and Atlantic Ocean[2] (Brazil). Two were global reviews[3,4].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** One global review[4] found that survival of unwanted sharks and rays at retrieval of longline gear was higher on nylon hook attachment lines instead of wire for two of three species and lower for one. One replicated, controlled study in the Atlantic Ocean[2] found that survival of unwanted sharks caught on tuna longlines was reduced with nylon hook lines compared to wire.

BEHAVIOUR RESPONSE (0 STUDIES)

OTHER (4 STUDIES)

- **Reduction of unwanted catch (4 studies):** One of two replicated, controlled studies in the Norwegian Sea[1] and Atlantic Ocean[2] and one of two reviews of worldwide longline fisheries[3,4] found that modifying longline configuration (increasing the lead weight on mid-water longlines to increase the sinking rate[1] and using nylon instead of wire hook attachments[2,3,4]) reduced the catches of unwanted sharks and/or rays[2,4] compared to standard longlines. One study[3] found that longline modifications reduced unwanted shark/ray catches in one of two cases. The other[1] found that modified longlines did not reduce catches of undersized haddock compared to standard longlines.

Background

Avoiding the capture of unwanted fish in longline fisheries or reducing the damage to hooked fish helps reduce fishing mortality and improve survival after release (Amengual-Ramis *et al*. 2016). Modifying the parts of a longline may make it more difficult for certain species or sizes to approach and consume the baited hooks.

Evidence for similar interventions affecting the capture of fish on hook and line is summarized under *'Fishing gear modification - Use a different hook type'* and *'Use a different bait type'*. See also, *'Deployment of fishing gear and mode of operation - Deploy fishing gear at selected depths to avoid unwanted species'*.

Amengual-Ramis J.F., Vazquez-Archdale M., Canovas-Perez C. & Morales-Nin B. (2016) The artisanal fishery of the spiny lobster *Palinurus elephas* in Cabrera National Park, Spain: comparative study on traditional and modern traps with trammel nets. *Fisheries Research*, 179, 23–32.

A replicated, controlled study in 1995–1996 of two coastal pelagic areas in the Norwegian Sea, north Norway (1) found that increasing the lead weight on mid-water longlines to increase the sinking rate, did not typically reduce the catches of undersized haddock *Melanogrammus aeglefinus* compared to longlines with normal lead weight. The proportion of haddock below legal size (44 cm) was similar for both weights in three of four trials (double weight: 17–25%, normal weight: 16–21%) and catch rates were also similar (double: 52–70 fish/100 hooks, normal: 46–74 fish/100 hooks). In one of four trials however, the proportion of haddock below legal size was lower with double lead weight (double: 13%, normal: 17%) and haddock catch significantly higher (double: 91 fish/100 hooks, normal: 68 fish/100 hooks). Trials were carried out in July 1995 and June/July 1996 by two commercial longliners. Four separate trials were done, one by each vessel in one area both years. Each vessel fished a different number of hooks/rigging configuration (see paper for specifications), all baited with mackerel. The lead weight on sets of longlines was doubled and the sets deployed alternately with lines with normal lead weight. A total of 14,022 and 26,353 hooks were set for modified lines and normal lines respectively. Numbers of fleets deployed, or their distances apart, were not specified. Numbers and lengths of captured haddock were recorded.

A replicated, controlled study in 2011 in an area of pelagic water in the southwestern Atlantic Ocean off Brazil (2) found that modifying the configuration of tuna fishery longlines by using a nylon tether instead of a steel wire tether to suspend the hooks reduced the overall capture of unwanted sharks, but also reduced shark survival. Catch rates of all sharks combined were lower on nylon tethers than steel, irrespective of hook type (nylon: 4 sharks/1,000 hooks, steel: 8 sharks/1,000 hooks). However, if hooks that were bitten off were included (assumed to be by sharks) no effect of tether type was found (nylon: 8–12 sharks/1,000 hooks, steel: 8 sharks/1,000 hooks) and almost all occurred on nylon tethers. On nylon tethers only 34% of the shark catch (n=56) was alive compared to 54% (n=86) on steel tethers. Data were collected in January 2011 from 17 longline set deployments on a commercial fishing vessel. Longlines were made of nylon monofilament (3.5 mm diameter) and 90 km length. Each set had 1,000 hooks (total 17,000 hooks), randomly arranged with either nylon or stainless steel tethers and circle or J shaped hooks, baited with squid *Illex* sp.

A review in 2013 of two studies in a meta-analysis of 27 studies to assess methods to reduce unwanted shark and ray (*Elasmobranchii*) catches in longline fisheries worldwide (3) found that modifying the configuration of longlines by using nylon lines instead of wire lines to attach the hooks to the main longline reduced the overall amount of unwanted sharks and rays caught in one of two cases. Numbers of sharks and rays caught on breakable monofilament lines were 58% lower than on wire lines. However, tarred multifilament nylon lines (designed to make them easier for fish of all species to see and avoid) caught similar numbers of sharks and rays to traditional wire branch lines (data reported as graphical analysis). The systematic review summarized 44 datasets from 27 studies of the effects of various actions to reduce unwanted shark and ray catch, and identified one study comparing breakable monofilament nylon lines with wire lines and one comparing tarred multifilament lines instead of wire lines. Full literature search methods are reported in the original paper.

A review of 41 worldwide studies in 2016 of various methods to reduce unwanted shark and ray (*Elasmobranchii*) catches in pelagic longline fisheries (4) found that modifying the configuration of longlines by using monofilament leader lines (to attach the hooks) instead of wire reduced the number of unwanted elasmobranchs caught, and survival at retrieval varied between species. Catch rates of elasmobranchs were lower for seven of 10 unwanted elasmobranch species using monofilament leader lines rather than wire, and higher for three species. Survival at gear retrieval was higher on monofilament leader lines for two of three species and lower for one compared to wire lines. The study performed a meta-analysis of 41 studies globally on the effects of different hook and bait types in pelagic longline fisheries on unwanted elasmobranch catch rates and survival.

(1) Huse I. & Soldal A.V. (2000) An attempt to improve size selection in pelagic longline fisheries for haddock. *Fisheries Research*, 48, 43–54.
(2) Afonso A.S., Santiago R., Hazin H. & Hazin F.H.V. (2012) Shark bycatch and mortality and hook bite-offs in pelagic longlines: Interactions between hook types and leader materials. *Fisheries Research*, 131–133, 9–14.
(3) Favaro B. & Côté I.M. (2015) Do by-catch reduction devices in longline fisheries reduce capture of sharks and rays? A global meta-analysis. *Fish and Fisheries*, 16, 300–309.
(4) Gilman E., Chaloupka M., Swimmer Y. & Piovano S. (2016) A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. *Fish and Fisheries*, 17, 748–784.

2.37 Modify gillnet or entangling (trammel/tangle) net configuration

- **Four studies** examined the effects of modifying gillnet or entangling (trammel or tangle) net configuration on marine fish populations. One study was in each of the Gulf of Maine[1] (USA), the

Atlantic Ocean[2] (USA) and the Adriatic Sea[3] (Italy), and one study was in two estuaries in North Carolina[4] (USA).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (4 STUDIES)

- **Reduction in unwanted catch (4 studies):** Three of four replicated studies (one controlled, two paired and controlled) in the Gulf of Maine[1], Atlantic Ocean[2], Adriatic Sea[3] and estuaries in USA[4], found that modifications to the configuration of gillnets, including reduced height[1], increased tension[2], twine diameter[3] and mesh orientation[4], reduced the unwanted catch of cod in one of two net designs[1], discarded fish of commercial and non-commercial species[4], and the discards of non-commercial, but not commercial species (fish and invertebrates)[3], compared to conventional configurations. The other study[2] found that gillnet modification did not typically reduce unwanted shark catches compared to unmodified gillnets.

Background

Gillnets are walls of single netting hung vertically on the seabed or in the water column, in which fish get stuck by their gills. Trammel and tangle nets (also known as entangling nets) are variations of the gillnet, used in a similar way, and may be single, double or three-walled nets in which fish or crustaceans will entangle. All of these types of net are commonly used in commercial fisheries and can be set at any depth on a range of bottom-types (Carol & García-Berthou 2007). They have floats on the upper line and weights on the bottom line and can be set anchored to the bottom or left drifting, free or connected to a vessel. Gillnets are considered as relatively selective fishing gears, in terms of fish species and sizes, but entangling nets will catch a wider variety of fish sizes. To help reduce unwanted catch, modifications to the configuration of gillnets and entangling nets may change how they fish in the water, allowing some fish to avoid capture. The behaviour of individual fish species may also influence how effective the net is at allowing escape.

Evidence for a related intervention is summarized under '*Fishing gear modification – use a larger mesh size*'.

Carol J. & García-Berthou E. (2007) Gillnet selectivity and its relationship with body shape for eight freshwater fish species. *Journal of Applied Ichthyology,* 23, 654–660.

A replicated, controlled study in 2003 of an area of seabed in the Gulf of Maine, off New Hampshire, USA (1) found that modifying the configuration of a bottom gillnet (reducing the net height/number of meshes) reduced the unwanted catches of cod *Gadus morhua* in one of two net designs, compared to two nets of standard height. Cod catch rates were lower in one of two reduced height gillnets (eight meshes deep) compared to the other reduced height net (12 meshes deep) and two types of standard net of 25 meshes height (eight mesh: 8; 12 mesh: 14; standard cod net: 32, tie-down flounder net: 11 fish/five-net fleet). In addition, the eight mesh net had higher catches of the targeted flounder *Pleuronectidae* species than one of the standard 25 mesh nets (cod net), but lower than the other (flounder net) (eight mesh: 5, standard cod net: 4, tie-down flounder net: 11 fish/five-net fleet). During July and August 2003, forty comparative fishing sets of four types of gillnet (see paper for specifications) were fished on the seabed at depths between 34–76 m, at random locations in the same general area within half a mile apart. The gillnets were left overnight for 18–28 hr.

A replicated, paired, controlled study in 2000 of two coastal fished areas in the Atlantic Ocean, off the coast of North Carolina, USA (2) found that modifying the configuration of a gillnet by increasing the tension did not typically reduce the catch rates of four unwanted shark species in a commercial gillnet fishery, compared to unmodified nets. Shark catch rates were reduced in gillnets with increased tension only in nets of the larger mesh size (10.2 cm) and only for two of four species: Atlantic sharpnose *Rhizoprionodon terraenovae*, (modified: 0.35, unmodified: 0.58 kg/gillnet/hr) and blacknose *Carcharhinus acronotus* (modified: 0.04, unmodified: 0.13 kg/gillnet/hr); but not blacktip *Carcharhinus limbatus* (0.09 vs 0.13 kg/gillnet/hr) or bonnethead sharks *Sphyrna tiburo* (0.23 vs 0.31 kg/gillnet/hr). Catch rates of all four species were not significantly different between nets of 7.6 cm mesh size (modified: 0.05–2.11; unmodified: 0.08–2.46 kg/gillnet/hr). In addition, there was no difference in catch rates of the target fishery species Spanish mackerel *Scomberomorus maculatus* between modified and unmodified gillnets of the same mesh size (see paper for data). Data was collected from deployments of four gillnets of two mesh sizes (7.6 and 10 cm) by a commercial fishing vessel in May-September 2000. For each mesh size, one gillnet had increased tension (using larger floats on the top-rope and heavier weights on the bottom rope) and was set end to end (15 m apart) with the other, unmodified, net. Between 24–34 sets were made with each mesh size.

A replicated study in 2010 of an area of sandy-mud seabed in the Adriatic Sea, Italy (3) found that modifying the configuration of a gillnet by increasing the twine diameter reduced the discards of non-commercial, but not commercial, species (fish and invertebrates). The percentage of discarded non-commercial species (fish and invertebrates) in catches decreased with increases in twine diameter (0.30 mm: 27%, 0.25 mm: 30%, 0.22 mm: 33%, 0.20 mm: 41%, 0.18: 39%), but there was no differences between diameters for discarded commercial species (5–7%). The average number of species caught was also lower for the thickest twine diameter compared to the three thinnest (0.30 mm: 7, 0.25 mm: 8, 0.18–0.22 mm: 9). In addition, catch rates of the target fish species, common sole *Solea solea*, were similar between twine diameters (data reported as statistical results). During July–October 2010, a total of 20 gillnet sets (deployments) were fished for 10–12 h. For each set, 50 single-twine gillnets (10 of each twine diameter: 0.18, 0.20, 0.22, 0.25 and 0.30 mm) were randomly arranged in one group, 1.5 m apart. All species caught were identified and separated into commercially valuable catch and unwanted catch.

A replicated, paired, controlled study in 2010–2013 of two estuaries in North Carolina, USA (4) found that rectangular mesh gillnets of different mesh sizes and depths reduced catches of unwanted fish including red drum *Sciaenops ocellatus* and undersized individuals of the commercial target species southern flounder *Paralichthys lethostigma* compared to conventional diamond mesh nets. Numbers of unwanted fish were lower in rectangular mesh nets than diamond mesh, irrespective of the depth profile (number of meshes) of the net (rectangle: 0.4–0.5 fish/90 m, square: 4.1–4.8 fish/90 m) and mesh size (rectangle: 0.4 fish/30 m, square: 1.2–1.4 fish/30 m). Red drum and undersized southern flounder catches were lower in rectangular than diamond meshes for both net depth profiles (red drum: 0.0 vs 0.2–0.3 fish/90 m; flounder: 0.0–0.1 vs 0.5 fish/90 m). Catches of both species were lower in rectangular nets compared to diamond mesh nets for two of three mesh size comparisons (14.0 and 15.2 cm mesh sizes for red drum and

14.6 and 15.2 cm for undersized flounder – see paper for data). Legal-sized catches of target flounder were similar in rectangular and diamond mesh nets for both low profile (0.9 vs 1.1) and high profile nets (0.4 vs 0.7/90 m), but lower in all three rectangular mesh sizes than corresponding diamond nets (14 cm: 0.2 vs 0.4, 14.6 cm: 0.3 vs 0.5, 15.2 cm: 0.1 vs 0.4/30 m). Experimental gillnet deployments were made in the Neuse River estuary in April–June 2010 and in the Newport River Estuary in April–October in 2011–2013. In 2010, paired deployments (85) of one of two rectangular mesh nets, 20 meshes ('low profile') and 33 meshes ('high profile') deep, and one diamond mesh gillnet (20 meshes deep), all 14 cm mesh size were made, set parallel to the shore for 12 h. In 2011–2013, a total of 150 paired deployments were made of three rectangular mesh nets and three diamond mesh nets of different mesh sizes (14.0 cm, 14.6 cm or 15.2 cm), set for 12 h parallel to shore.

(1) He P. (2006) Effect of the headline height of gillnets on species selectivity in the Gulf of Maine. *Fisheries Research*, 78, 252–256.
(2) Thorpe T. & Frierson D. (2009) Bycatch mitigation assessment for sharks caught in coastal anchored gillnets. *Fisheries Research*, 98, 102–112.
(3) Grati F., Bolognini L., Domenichetti F., Fabi G., Polidori P., Santelli A., Scarcella G. & Spagnolo A. (2015) The effect of monofilament thickness on the catches of gillnets for common sole in the Mediterranean small-scale fishery. *Fisheries Research*, 164, 170–177.
(4) Rudershausen P.J., Price A.B. & Buckel J.A. (2015) Can bycatch in a flatfish gillnet fishery be reduced with rectangular mesh? *Fisheries Management and Ecology*, 22, 419–431.

2.38 Modify fishing trap/pot configuration

- **Twenty-three studies** examined the effects of modifying fishing trap or pot configuration on marine fish populations. Five studies were in the Atlantic Ocean[2,5,12,20,22] (USA, Brazil, Canary Islands, Canada). Three studies were in each of the Bothnian Sea[10,14,18] (Sweden), the Baltic Sea[4,11,19] (Poland, Sweden), the Tasman Sea[3,13,23] (Australia) and the Indian Ocean[6,16,17] (Kenya, South Africa). One study was in each of the Kattegat[1] (Denmark), the Mediterranean Sea[7] (Spain), the Adriatic Sea[8] (Italy), the Southern Ocean[9] (Australia), the Pacific Ocean[15] (Canada) and the Barents Sea[21] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled study in the Bothnian Sea[14] found that survival of small herring escaped from a pontoon fish trap through a size-sorting grid was similar to trap-caught herring that did not pass through a grid.

BEHAVIOUR (0 STUDIES)

OTHER (22 STUDIES)

- **Reduction of unwanted catch (20 studies):** Sixteen of 20 replicated studies (11 controlled, one randomized, paired and controlled, one randomized and controlled, two paired and controlled and one randomized) and one before-and-after study in the Atlantic Ocean[2,5,12,20,22], Baltic Sea[4,11,19], Mediterranean Sea[7], Southern Ocean[9], Tasman Sea[13,23], Adriatic Sea[8], Bothnian Sea[10,18], Indian Ocean[16,17], Pacific Ocean[15], the Kattegat[1] and the Barents Sea[21], found that modifications to trap configuration (various, including using a different trap type, increased mesh size and fitting an escape device) reduced the unwanted (undersized, discarded or non-commercial target) catches of fish (overall, or all of multiple study species)[4,7,12,13,16,17,19], brown trout[1], black sea bass[2], herring[10], bluethroat wrasse and leatherjacket[9], cod[11], protected rockfishes[15], whitefish[18], black sea bass[20], American eel and winter flounder[22], sharks/rays[23] and of salmon and rainbow trout in one of two cases[1], compared to unmodified conventional traps or traps of other designs. One of these[22] also found that the number of unwanted species (fish and invertebrates) was lower in modified traps. Three other studies[5,8,21], found that trap modification or type had no effect on unwanted catches of white croaker[5], non-commercial fish[8] or undersized Atlantic cod[21], and non-target haddock catches were increased[21]. However, one of these[8] also reported that traps (creels) did not catch high proportions of immature fish, unlike bottom trawls.

- **Improved size-selectivity of fishing gear (4 studies):** Three of four replicated studies (two controlled and one randomized, paired and controlled) in the Baltic Sea[11], Tasman Sea[3], Indian Ocean[6] and Atlantic Ocean[20] found that traps or pots modified with a square mesh escape window or larger mesh sizes improved the size-selectivity of Atlantic cod[11], black sea bass[20] and most fish species[3] compared to smaller mesh and/or standard gear. The other[6] found that increasing mesh size of a trap escape panel had no effect on size-selectivity of panga.

Background

Fishing traps are a widespread traditional method for catching fish and crustacean species. They are passive gears, relying on bait or tidal currents to catch the desired species. Traps vary widely in design and are commonly in the form of portable pot- or bottle-shaped cages. However, some fishing nets are also called fish traps (e.g. fyke nets) and consist of much larger fixed or semi-fixed structures involving several sections of staked netting leading to a collecting bag/basket. The type and location of traps depends on the species being targeted. Types that target adult fish and eels (e.g. pound nets or fyke nets) or certain crustacean species like prawns/shrimps, may also catch considerable quantities of immature fish. In certain conditions (e.g. shallow estuaries in summer), trapped immature fish may die before they are released. Fish caught in crustacean traps may also suffer damage and mortality caused by the commercially targeted species. Modifications to traditional trap designs may help to prevent unwanted fish species or sizes from being retained in traps and thus reduce fish mortality.

A replicated, controlled study in 1992–1993 of five areas in a shallow estuary in the Kattegat, Denmark (1) found that modifications made to eel pound nets (fine-mesh, passive fish traps) reduced the capture of unwanted young brown trout *Salmo trutta* and, for one of two methods, salmon *Salmo salar* and rainbow trout *Oncorhynchus mykiss*, compared to nets fished without the modifications. The first of two modifications, submerging the pot net (the last enclosure in the net before the fyke net – akin to a codend), reduced catches of all species: by 91% for brown trout; 86% for salmon; and 75% for rainbow trout. The second, raising the guard net (located at the entrance to the pound net) to the surface using floats reduced numbers of brown trout (raised: 5–25 fish, not raised: 14–60 fish) but not salmon (raised: 6–18 fish, not raised: 13–15 fish) or rainbow trout (raised: 2–4 fish, not raised: 1–2 fish). In addition, catches of legal-sized individuals of the target eel *Anguilla anguilla* were similar for both comparisons. Pound net fishing was done in April/May 1992 and 1993 at five locations in the Randers Fjord estuary (22 km^2), eastern Jutland, in 2–4 m depth. Every one or two days, pound nets were changed from a standard configuration to a modified one, either with a surface floating guard net or with submerged pot net, and vice versa. For the submerged nets, three different depths were fished: 55, 75 and 100 cm below sea level. The daily catch in each pound net was recorded as the number of each species from both the pot and fyke net sections within a 24 h period.

A replicated, randomised, controlled study in 1994 of an area of shallow seabed in the Atlantic Ocean off Delaware, USA (2) found that fish traps modified with escape vents reduced the unwanted catch of undersized black sea bass *Centropristis striata* compared to traps without escape vents. Across all escape vent sizes, catch rates of bass (all sizes) were lower in traps with vents than without (with: 2–11 bass/trap, without: 10–14 bass/trap) and the average bass size was greater (with: 27 cm: without: 25 cm). The proportion of undersized (<24 cm) bass in traps with vents was reduced by 72–95% compared to without, and the reduction increased with increasing vent size (2.9 cm: 288 bass, 3.2 cm: 80 bass, 3.5 cm: 59, 3.8 cm: 48 bass, no vent: 1,037 bass). Data were collected from 893 trap deployments (18–27 m) during nine trips between May-November 1994. Traps were deployed along lines (strings) of 25 traps in blocks of five trap designs, four with escape vents of different sizes (2.3 cm, 3.2 cm, 3.5 cm and 3.8 cm) and one standard trap without vents. Four strings of 25 traps were set/trip and traps were randomly positioned within a block. Strings were set 5 miles apart and left for 12–32 days before retrieval.

A replicated, controlled study in 1999–2000 of three fished areas of seabed in the Tasman Sea off New South Wales, Australia (3) found that bottom traps modified with back panels of different and larger mesh type improved the size selectivity of the majority of fish species, compared to the standard commercial trap. For five of 10 species, the estimated size at which fish had a 50% chance of escape (selection size) was greater for modified traps than standard traps (modified: 21–35 cm, standard: 15–25 cm). For four species, the selection size in modified traps was 17–24 cm, whereas all individuals were predicted to be retained in standard traps (see paper for size ranges – reported as length frequency curves). All sizes of one species were retained in both modified and standard traps. See original paper for individual data by species. Data were collected on chartered commercial vessels commercial fishing grounds in three locations during March–October 1999. Deployments were made of three different fish traps, identical (all covered with 37 mm hexagonal wire mesh) except for their back panels: a modified back panel of 50 mm × 75 mm welded mesh (122 trap lifts), a standard back panel of 50 mm hexagonal wire mesh (129 trap lifts), and a smaller 37 mm hexagonal wire mesh to retain and sample all sizes (104 trap lifts). Traps were baited and left on the seabed for 24–72 hours. Fish lengths from the nose to the end of the backbone (fork length) were measured.

A replicated, controlled study in 1999–2004 of three sand and mud seabed areas in Vistula Lagoon, Baltic Sea, Poland (4) found that fyke nets modified with protective sieves (a bycatch reduction device) retained fewer undersized and unwanted individuals of four of four commercial fish species compared to conventional fyke nets without protective sieves. In catches with sieves, the length frequencies of the four most important commercial fish species differed to catches without sieves, with fewer fish of smaller sizes (data presented graphically) and higher average lengths (bream *Abramis brama*: 29 vs 20 cm, pikeperch *Sander lucioperca*: 26 vs 16 cm, roach *Rutilus rutilus*: 18 vs 15 cm, perch *Perca fluviatilis*: 18 vs 14 cm). Incidental fish catch was sampled at three sites in the brackish Vistula Lagoon (838 km^2) from commercial fyke net catches targeting European eel *Anguilla Anguilla*. In May 2004, the fyke nets sampled (12 deployments) were fitted with selective sieves with openings of 20 × 65 mm to allow fish escape. In May 1999 standard fyke net deployments (22) were sampled (see paper for gear specifications). Captured fish were sorted by species, weighed, and their lengths measured.

A replicated, paired, controlled study in 1999–2000 in a shallow sandy estuary in the Atlantic Ocean, Brazil (5) found that fitting size-sorting escape grids to stationary shrimp net traps (stow nets) did not reduce the unwanted catch of white croaker *Micropogonias furnieri* compared to standard shrimp traps without a grid. For grid bar spacings of 25, 30 and 35 mm, unwanted catch of white croaker was not significantly different between nets (with grid: 16–39 fish, without grid: 28 fish). In addition, there was no significant difference in catches of target pink shrimp *Farfantepenaeus paulensis* between nets with and without grids (all bar spacings; with: 1,783–2,128 shrimps, without: 2,110 shrimps). Trials were done in the Patos Lagoon in late-1999–February 2000. Three commercial shrimp nets were fitted with a circular metal grid with one of three bar spacings (25, 30 or 35 mm) and one standard net was left without a grid. The nets were positioned randomly, and the grids changed between nets. Ten samples were taken, with each net fishing at the same time. Nets were set in the evening and retrieved at the end of the night. All catch was weighed, and fish were counted and identified.

A replicated study in 2002–2004 in an area of seabed in St Francis Bay in the Indian Ocean, off South Africa (6) found that modifying fish traps by increasing the mesh size of the escape panel had no effect on the size-selectivity of commercial target panga *Pterogymnus laniarius*. The average height of panga in catches was similar between all three relative mesh sizes of the trap escape panels (large: 97 mm, medium: 95 mm, small: 95 mm). In addition, the effect of mesh size on catch species composition, including non-target fish, was not reported, however, it differed with depth and substrate type (see paper for data). Data were collected from 59 trap deployments between September 2002 and July 2004. Three pairs of traps were used during most deployments, each fitted with a different mesh size of escape panel: two large (50 ×100 mm mesh), two medium (50mm × 75mm mesh) and two small (50 × 50 mm mesh). Traps were deployed randomly in depths of 20–99 m and for 2–8 hours. Fish in catches were identified and counted. The sizes of panga, including body height, were recorded.

A replicated, controlled study in 2006 in a lagoon channel in Alfacs Bay in the Mediterranean Sea, Spain (7) found that eel *Anguilla anguilla* traps with a modified entrance typically reduced the catches of unwanted fish compared to unmodified conventional traps. Overall, the proportion of unwanted fish (all species) was lower in modified traps (63%) than in conventional traps (37%). For individual species, the proportions of young thinlip mullet *Liza ramada* and golden grey mullet *Liza aurata* were also lower in modified traps (thinlip: 4%, grey: 21%) than in conventional traps (thinlip: 96%, grey: 79%). Catches of unwanted common goby *Pomatoschistus microps*, sand smelt *Atherina boyeri*, Spanish toothcarp *Aphanius iberus* and juvenile Senegalese sole *Solea senegalensis* were also lower in modified than conventional traps (data reported as statistical model results). Catches of unwanted black-striped pipefish *Syngnathus abaster*, sea bass *Dicentrarchus labrax* and juvenile gilthead seabream *Sparus aurata* were similar in each trap design (data reported as statistical model results). In addition, proportions of commercial target eel catches were not significantly different between modified (63%) and conventional (37%) trap designs. Modified and conventional traps were deployed on opposite sides of a channel in 23 trials. All traps were a trapezoid frame covered with small mesh (2 mm) and with a funnel entrance. Modified traps had a rigid square-meshed cylinder at the end of the entrance funnel to prevent unwanted species entering the trap.

A replicated study in 2004 in an area of seabed in the Adriatic Sea, Italy (8) found that trap (creel) type did not typically affect the catch of non-commercially targeted fish species, however compared to bottom trawl gear, creels did not catch high proportions of immature fish of commercial species. Overall, the percentage of creels containing non-target species (fish and invertebrates other than Norway lobster *Nephrops norvegicus*) was similar between Scottish (14%) and Croatian (6%) creels, but for both designs it was lower than for the Italian creel design (52%). However, only two of the 11 catch species were fish, and these were caught in Scottish creels only (<1 fish/creel). By comparison (but not tested statistically) 30 of the 55 species caught in bottom trawl deployments for lobster were fish, including a large proportion of immature individuals of commercial and other species (see paper for data). Data were collected from deployments of three different creel designs and a traditional commercial bottom trawl (11 hauls) in the western Pomo pit in August 2004 (see original paper for gear specifications). Traps were soaked for 24 h at depths of 210–235 m. On each of two deployments, two fleets were shot, one with 81 Scottish creels and the other with 40 Croatian and 20 Italian creels interspersed. Two further deployments were made of Scottish creels only. Trawl hauls were 1 h.

A before-and-after study in 2000–2008 in a fished area of seabed in the Southern Ocean off South Australia (9) reported that catches of unwanted blue-throat wrasse *Notolabrus tetricus* and leatherjacket *Meuschenia* spp. were lower after the introduction of escape gaps to lobster traps. Data were not statistically tested. In 2000 and 2001, unwanted catches of wrasse were 0.12 and 0.09 wrasse/pot respectively, while catches of leatherjacket were 0.28 and 0.36 leatherjacket/pot. In 2003 after escape gaps in lobster pots had been introduced, wrasse catches were 0.05 wrasse/pot and remained between 0.05–0.06 wrasse/pot in the period until 2008. Leatherjacket catches were 0.13 leatherjacket/pot in 2003 and remained below 0.22 leatherjacket/pot until 2008. Escape gaps also reduced catches of undersized commercial target rock lobster *Jasus edwardsii* by 64%. In 2003, two escape gaps (minimum 5.7 cm height x 28 cm width) were made mandatory at each end of lobster pots in the Northern Zone rock lobster fishery in the Great Australian Bight. Catch rates of undersized lobster and unwanted fish species for the period 2000–2008 were obtained from a voluntary logbook programme established in 2000.

A replicated study in 2010 in nine inshore areas in the Bothnian Sea, Sweden (10) reported that herring *Clupea harengus* pontoon traps modified with two rigid size-sorting grids allowed the escape of high proportions of undersized herring. Data were not statistically tested. Across all trials, between 68–565 kg of the total weight of herring entering the traps (400–1,200 kg) was estimated to have escaped through the grids. By number, this was a reduction in catch of 17–76% (2,420–17,008 fish). The proportion of undersized herring removed from the catches (selection efficiency) was 54–72% across all trials. In addition, higher proportions of herring escaped through grids with 15 mm bar spacing (59–76%) than 14 mm grid bar spacing (17–25%). Data were collected from six deployments (17–120 h soak times) of a herring pontoon trap in May/July 2010. The trap was a single-walled cylindrical fish chamber (6 × 3 m) with small (24 mm) mesh to retain all sizes of herring. At each end of the chamber, a grid consisting of a 300 mm wide ring with 2 mm diameter stainless steel rods fitted vertically inside was fitted. The rods were placed at either 14 mm or 15 mm bar spacing (three deployments of each bar spacing). Underwater cameras monitored numbers of herring escaping through the selection grids. Full trap specifications are given in the original paper.

A replicated, randomized, paired, controlled study in 2009–2010 in shallow coastal waters of the Bay of Hanö in the Baltic Sea, Sweden (11) found that floating traps (pots) modified with square mesh escape windows allowed the escape of high proportions of undersized Atlantic cod *Gadus morhua*, and size-selectivity increased with increasing window mesh size. Pots with square mesh escape windows allowed the escape of over 90% of cod under the minimum landing size of 38 cm (data presented graphically). The length at which cod had a 50% chance of escaping increased with increasing mesh size of the escape window (40 mm: 32 cm, 45 mm: 38 cm, 50 mm: 40 cm). Data were collected in April 2009–January 2010 from a commercial fishing vessel. A total of 54 paired deployments were done of four pots with identical escape window mesh size (three different sizes: 40 mm, 45 mm and 50 mm), and four without windows, set randomly along a line (string). All pots were baited with Baltic herring *Clupea harengus* and soak-time was 1–14 days. See original paper for full gear specifications.

A replicated, controlled study in 2003–2004 of seabed and near seabed in the Atlantic Ocean off the Canary Islands, Spain (12) reported that semi-floating shrimp traps caught less unwanted fish catch (non-commercially targeted or discarded) catch than traditional bottom traps, and the difference decreased with depth. Data were not statistically tested. At 100–400 m depths, semi-floating traps caught 18 unwanted species of fish at catch rates between <0.1–858.9 g/trap/day, and bottom traps caught eight species at <0.1–24.9 g/trap/day. Between 401–800 m depth, semi-floating traps caught eight unwanted fish species (<0.1–2,241.0 g/trap/day) while bottom traps caught four species (0.4–140.6 g/trap/day). At the deepest depths (801–1,130 m), semi-floating traps caught five unwanted fish species (<0.1–186.4 g/trap/day) and four were caught in bottom traps (0.5–41.9 g/trap/day). At all but the deepest depths, conger eels *Conger conger* accounted for a large proportion of the unwanted catch in bottom traps and in semi-floating traps at the intermediate depths (see paper for species individual data). Target shrimp *Plesionika* spp. catches between floating and bottom traps varied with species and depth (see paper for data). Four research surveys were done around the Canary Islands in 2003–2004 at depths of 100–1,300 m. Two types of traps were used to target shrimp: semi-floating traps of plastic mesh (20 ×15 mm) covering a conical cylinder (56 × 57 cm), and bottom traps made of wire mesh (19 × 19 mm) and an iron rectangular frame (100 × 100 × 50 cm). Semi-floated traps were set in groups of 75 traps, 15 m apart and 2 m above the seabed (total 1,971). Bottom traps were deployed in lines of 10 traps, 50 m apart (total 487). All traps were deployed in daylight hours and baited with mackerel *Scomber colias*.

A replicated study in 2010 of mud and sand seabed in two estuaries in the Solitary Islands Marine Park in the Tasman Sea, Australia (13) found that the number of unwanted fish caught in traps in a mud crab *Scylla serrata* fishery was lower in three of four trap designs. Across six days of fishing, unwanted fish catches (consisting mainly of yellowfin bream *Acanthopagrus australis*) in hoop nets (3 fish), rectangular pots (9 fish) and wire pots (5 fish) were lower than in round pots (287 fish). In addition, all trap designs retained similar sizes of commercial target mud crabs (8–19 cm). Between February and June 2010, five traps of each of four designs were deployed for three, six or 24 hours across six days of fishing. Designs were: steel-framed hoop traps (0.75 m diameter × 0.65 m, 150 mm mesh), rectangular collapsible plastic pots (0.88 × 0.55 × 0.20 m) with "V" shaped entrances, rectangular wire pots (0.90 × 0.60 × 0.30 m) with 50 x 0.75 mm wire mesh and two funnel entrances, and round, collapsible plastic pots (0.90 m diameter × 0.27 m) with four funnel entrances. All traps complied with existing regulations and were baited with sea mullet *Mugil cephalus* in a 10 × 10 mm mesh bag, and deployed 50–100 m apart.

A replicated, controlled study in 2010 in an inshore area of the Bothnian Sea, Sweden (14) found that survival rates of trap-caught small Baltic herring *Clupea harengus* *membras* that had passed through a size-sorting escape grid were similar to trap-caught herring that had not passed through a grid. The mortality of herring that had passed through the escape grid was 3–13% compared to 7–45% for herring caught without a grid. When the effects of water temperature variations during the trials were considered, no significant difference in mortality rates between traps was found. Herring were sampled in a herring trap (pontoon trap) in six alternate trials in July-September 2010: three using a stainless steel sorting grid with 14 mm bar spacing and three with no grid. Small herring were caught in the trap by passing through a sorting grid mounted at the entrance of the fish chamber. The trap was then closed and the herring retained in situ for seven days. As control fish, herring of all sizes were trapped without passing through any grid. Numbers of herring enclosed varied between 172 and 2,170. For each trial, herring survival rates after the seven days were assessed.

A replicated, randomized, controlled study in 2010 in two areas of seabed in the Strait of Georgia, in the Pacific Ocean, British Columbia, Canada (15) found that two of five modified designs of traps commercially targeting spot prawns *Pandalus platyceros* caught fewer unwanted fish and protected rockfish *Sebastes* spp. compared to a conventional unmodified trap. Overall, unwanted fish catches were 69% and 68% lower in the five and seven-ring tunnel-equipped traps than the conventional traps respectively, but unwanted fish catch rates in the three other modified trap designs were similar to the conventional trap (data presented graphically – see original paper). Only six rockfish were caught overall: none in tunnel-equipped traps, one in the 6.4 cm entrance trap, two in the 7.0 cm entrance trap and three in the unmodified trap. In addition, average rockfish body weight and length were lower in traps with a five-ring tunnel and both five and seven-ring tunnel entrances respectively, compared to other designs (data reported as statistical model results). In addition, all modified traps caught fewer and generally smaller commercial target prawns than conventional traps (data reported as statistical model results). Traps were randomly ordered in groups of 10 along single weighted lines at 50–120 m depths. All traps were truncated cone designs with 3.8 cm mesh. Conventional traps (7.6 cm single-ring entrances) were compared to five modified designs with either a reduced diameter entrance (7.0 cm or 6.4 cm), or a tunnel-design 7.6 cm entrance of four, five or seven rings (see original paper for gear specifications).

A replicated, controlled study in 2012 at two coral reef sites in the Indian Ocean, Kenya (16) found that traditional traps with added escape gaps reduced the catches of unwanted fish compared to unmodified traps. Across both sites, biomass of non-commercial reef fish catch was lower in modified traps (40–210 g/trap) compared to unmodified traps (242–328 g/trap). At one site, commercial catch was similar between the trap designs (502–827 g/trap) and at the other site commercial catch was greater using the modified trap (1,376 g/trap) compared to the unmodified design (1,032 g/trap). Data were collected at a fish landing site between January-April 2012, from trap catches by fishers from two areas of the Mpunguti Marine National Reserve (10 km^2, established 1978). Fish catch weights were sampled from 77 catches using modified traditional traps (two 3 × 30 cm escape gaps) and 161 catches using unmodified traditional traps (161 samples).

A replicated, controlled study in 2011 of a fished area of seabed in the Indian Ocean, Kenya (17) found that modified fish trap designs (escape slots of four different sizes) reduced the catches of smaller unwanted fish compared to unmodified traps. Average fish length and weight were greater in the modified traps for three of the four slot widths compared to the unmodified trap (length: 21–26 vs 20 cm/trap; weight: 208–424 vs 178 g/trap). The catch percentages of immature fish were lower in modified traps (19–37%) than unmodified traps (50%). Between September–October 2011, catches from fishing grounds local to Kibuyuni (2–3 km radius) were sampled. Catches in local fishing traps of weaved wood fibre without escape slots were compared with modified traps with escape slots of varying widths (2, 4, 6, 8 cm). Five fishers participated in 12–24 days of experimental fishing with 108 samples analysed/trap design. Traps were set for 24 h and checked daily.

A replicated, controlled study in 2012 in an inshore area in the Bothnian Sea, Sweden (18) found that a pontoon fish trap modified with a square mesh escape panel fitted in the fish chamber reduced the catches of immature whitefish *Coregonus maraena* compared to traps without a panel. The proportion of undersized (<30 cm) whitefish in catches was 9% in modified traps and 32% in unmodified traps. A total of 72% of the whitefish <30 cm was estimated to have escaped through the panel that would otherwise have been captured. The number of whitefish caught in the modified trap was lower (488 fish) than the unmodified trap (1,003 fish). Data were collected from 28 deployments (9 m depth) of two pontoon traps fished at the same time 800 m apart between June-August 2012. The fish chamber with and without a 50 × 50 mm square mesh panel were exchanged between traps every two weeks (four replicates). See original paper for trap specifications. Escaping fish were sampled by video cameras attached next to the panel.

A replicated, controlled study (year not provided) in two coastal brackish sites in the Gulf of Bosnia, Baltic Sea, Sweden (19) found that pontoon traps fitted with a size-sorting escape grid reduced the catches of small fish compared to traps without a grid. The proportion of the total catch of small perch *Perca fluviatilis*, whitefish *Coregonus maraena* and roach *Rutilus rutilus* in traps fitted with a grid (0–55%) was lower than traps fished without a grid (56–90%). In addition, average size of perch, whitefish and roach caught in traps with grids was larger (grid: 28–37 cm, no grid: 22–31 cm). Fish were sampled with two different types of pontoon trap used for perch fishing (see paper for specifications). The traps were located at two sites for a total of 27 fishing periods, in June-August. Each trap was fitted with a 30 x 40 cm size-sorting grid of vertical 2 mm stainless steel bars with 30 mm bar spacing. Grids were covered with fine-meshed netting for nine of the fishing periods to sample catches without a grid. All fish caught in the traps were measured. Sampling year was not reported.

A replicated, controlled study in 2013 of an area of seabed in the Atlantic Ocean, USA (20) found that traps with larger mesh sizes improved the size-selectivity of black sea bass *Centropristis striata* and reduced the catches of undersized individuals, compared to conventional smaller mesh sizes. The length at which bass had a 50% chance of escape increased with increasing trap mesh size (64 mm mesh: 325 mm, 57 mm mesh: 290 mm, standard 51 mm mesh: 260 mm, standard 38 mm mesh with 51 mm back panel: 245 mm). The average catch rate of bass below the minimum landing size (<279 mm) decreased with increasing mesh size (64 mm mesh: 0 fish/trap, 57 mm mesh: 1 fish/trap, standard 51 mm mesh: 6 fish/trap, standard 38 mm mesh with 51 mm back panel: 9 fish/trap). Data were collected in Onslow Bay (sampling season not reported) from 350 deployments of five different trap types, all of square mesh: 64 mm mesh, 57 mm mesh, 51 mm mesh, 38 mm mesh with a 51 mm back panel, and one small mesh trap (38 mm) to sample all sizes of fish (between 33 and 119 deployments each). Traps were baited and set on the seabed at least 100 m apart for 1–12 hours. All bass were counted, and total length measured.

A replicated, controlled study 2007 in an area of seabed in the Barents Sea, Norway (21) found that modified floating pots (one entrance) did not reduce the amount of undersized commercial target Atlantic cod *Gadus morhua* compared to conventional pots with two entrances, and increased the amount of non-target haddock *Melanogrammus aeglefinus*. Catch rates of undersized (<44 cm) cod were similar between one-entrance pots (2 cod/pot) and two-entrance pots (2 cod/pot). Catch rates of haddock (all sizes) were higher in one-entrance pots (1.3 haddock/pot) compared to two-entrance pots (0.6 haddock/pot); the proportions of undersized (<40 cm) haddock being 44% and 69% for one- and two-entrance pots, respectively. In addition, legal-sized (>43 cm) cod catches were higher in one-entrance pots (2 cod/pot) than two-entrance pots (1 cod/pot). In September 2007, a total of 140 floating cod pots (100 × 150 × 120 cm) were set for 24 h in Varangerfjord, Norway. Seventy pots were conventional two-entrance pots (25 x 15 cm entrance) and 70 pots were modified to have one entrance. Pots were set every 50 m along a groundline at 108–150 m depth, and baited with squid *Illex* sp.

A replicated, paired, controlled study in 2016 of four seabed sites in the Gulf of St. Lawrence, Canada (22) found that modifying a fyke net reduced the capture of unwanted American eel *Anguilla anguilla* and winter flounder *Pseudopleuronectes americanus* compared to unmodified, conventional fyke nets, and the overall number of unwanted species (fish and invertebrates) in catches decreased. Across sites, catch numbers of unwanted eel and flounder (the two main unwanted fish species caught) were lower in modified nets (eel: 3, flounder: 7) than unmodified nets (eel: 37 fish, flounder: 43). The species composition (fish and invertebrates) was different between nets (for fish, flounder and mummichog *Fundulus heteroclitus* accounted most for the reduced catch in modified nets) and the number of unwanted species was lower in modified nets (modified: 5 species, unmodified: 12 species). In addition, numbers of target catch of green crab *Carcinus maenas* were reduced in modified nets (modified: 1,791, unmodified: 6,637). Data were collected at four sites in Murray Harbour off Prince Edward Island in July 2016. At each site, a removable 'bycatch reduction device' was randomly assigned to one of two conventional fyke nets (used to target green crab) and both nets set 100 m apart for three sets of four consecutive 24 h deployments, the device being switched between nets/set. After each individual 24 h deployment, fyke nets were fished at low tide. The 'bycatch reduction device' consisted of a sloped barricade ramp attached to a removable hoop with an entrance slit designed to prevent entry of non-target species (see paper for gear specifications).

A replicated, controlled study in 2013–2014 in three areas of sandy seabed in the Tasman Sea off the coast of New South Wales, Australia (23) found that modified traps fitted with permanent magnets reduced the catches of unwanted sharks and rays (*Elasmobranchii*), compared to conventional traps with no magnets or traps fitted with non-magnetic material. Catch rates of sharks/rays in traps with magnets were lower (0.2/trap) than traps with no magnets (0.3/trap) and traps with non-magnetic material (0.3/trap). Commercial target snapper *Pagrus auratus* catches were higher in traps with magnets (1.1 kg/trap) than without magnets (0.8 kg/trap) and 1.0 kg/trap in traps with non-magnetic material. In addition, the presence of sharks/rays in traps reduced commercial target snapper catches by 34% (1.5 vs 2.3 kg/trap). Between December 2013 and August 2014, a total of 1,015 traps of three different designs were set in three areas of sandy seabed at 5–102 m depth. Traps had a wooden frame (180 × 120 × 80 cm) covered in 50 mm wire mesh with a 100 × 60 mm escape panel at the rear. Each trap design had three funnel entrances, either with or without four magnets (75 × 13 × 16 mm) or with four non-magnetic bars (same size as magnetic) attached to each funnel.

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2.39 Fit escape devices (panels/grids) to encircling nets

- **Three studies** examined the effect of fitting fish escape devices (panels or size-sorting grids) to encircling nets on marine fish populations. One study was in the Tasman Sea[1] (Australia), one was in the North and Norwegian Seas[2] (Norway) and one was in the Atlantic Ocean[3] (Portugal).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled study in the North and Norwegian Seas[2] reported no difference in the survival of saithe, but reduced survival of mackerel, between fish that had passed through a rigid size-sorting escape grid in a purse seine net and those that had not, after one month.

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (2 studies):** Two replicated studies (one controlled) in the Tasman Sea[1] and Atlantic Ocean[3] found that transparent panels of net[1] and a large-diamond mesh escape panel[3] fitted to fish seine nets, reduced the catches of unwanted small individuals of one of four commercially targeted fish[1] and unwanted or undersized fish[3], compared to conventional seine nets.
- **Improved size-selectivity of fishing gear (1 study):** One replicated, controlled study in the Tasman Sea[1] found that size-selectivity of one of four commercial fish species was improved in seine nets with transparent netting panels compared to without.

Background

Encircling fishing gears consist of most types of seine nets and also encircling gillnets or ring nets. They can be deployed by hand from the shore or by boat, or by powered gear on larger vessels. Encircling gears can have very large nets, or sweep the entire water column in shallow areas, meaning that large numbers of unwanted species can be caught as well as those being fished for. Species that are not commercially valuable are often discarded or thrown back dead, resulting in unnecessary mortality (Bellido *et al*. 2011, Feekings *et al*. 2012). The use of fish escape devices in encircling nets similar to those used in trawls, such as mesh windows/panels and size-sorting grids, may allow unwanted fish of certain sizes or species to escape from the nets as they are hauled in.

For interventions describing the use of escape panels or size-sorting grids in other gear types, see *'Fishing gear modification - Modify fishing trap/pot configuration'*, *'Fit mesh escape panels/windows to a trawl net'*, *'Fit rigid (as opposed to mesh) escape panels/windows to a trawl net'*, *'Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net'* and *'Fit a size-sorting escape grid (rigid or flexible) to a prawn/shrimp trawl net'*.

Bellido J.M., Santos M.B., Pennino M.G., Valeiras X. & Pierce G.J. (2011) Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? *Ecosystems and Sustainability*, 670, 317–333.

Briggs R.P. (1992) An assessment of nets with a square–mesh panel as a whiting conservation tool in the Irish Sea *Nephrops* fishery. *Fisheries Research* 13, 133–152.

Feekings J., Bartolino V., Madsen N. & Catchpole T. (2012) Fishery discards: Factors affecting their variability within a demersal trawl fishery. *PLoS ONE* 7.

A replicated, controlled study in 1998 of an area of sand and mud bottom in an estuary in the Tasman Sea, New South Wales, Australia (1) found that fish seine nets modified with transparent panels of netting improved the size-selectivity and increased the likelihood of escape of one of four commercially targeted species compared to conventional nets. The length at which fish had a 50% chance of escape was greater in modified nets than conventional nets for sand whiting *Sillago ciliata* (modified: 22.4 cm, conventional: 20.6 cm), and similar for three other commercial target species: sea mullet *Mugil cephalus* (modified:17.7 cm, conventional: 17.4 cm), flat-tail mullet *Liza argentea* (modified: 17.7 cm, conventional: 19.8 cm) and silver biddy *Gerres subfasciatus* (modified 12.2 cm, conventional: 12.3 cm). Percentage number (and weight) of fish escaping was higher in modified nets than conventional nets for flat-tail mullet (modified: 13%, conventional: 5%), but was not significantly different for sand whiting (modified: 50%, conventional: 48%), sea mullet (modified: 16%, conventional: 19%) and silver biddy (modified: 76%, conventional: 47%). In January–February 1998, a total of 15 shallow fish seine net deployments were made in Bellinger River estuary, New South Wales: 10 of a net modified with two transparent mesh panels (57 mm mesh size, 100 × 50 meshes long) in the wings leading to the codend, with and without a cover to sample the escaping fish; and five of a conventional seine net, with a codend cover (see paper for specifications of nets).

A replicated, controlled study in 1993–1995 at four coastal pelagic sites in the North Sea/Norwegian Sea, Norway (2) found that using a rigid size-sorting escape grid in a purse seine net resulted in no difference in the survival of saithe *Pollachius virens* that had escaped through the grid, but survival of mackerel *Scomber scombrus* appeared reduced, compared to fish that did not pass through a grid. These results were not tested for statistical significance. Survival of saithe one month after capture was 97–100% for fish following use of an escape grid and 100% for fish that had not been through an escape grid. However, mackerel survival one month after capture was 18–56% for grid-escaped fish and 45–95% for fish that had not been through an escape grid. Three mackerel fishing trials were done by chartered purse seiners in August-September 1993–1995 at three coastal sites. Two saithe trials were done at one coastal site in April 1994 and by research vessel. Mackerel or saithe were captured by purse seine nets and towed inshore to large net pens. Fish that had passed through an escape grid were separated from fish that were caught in purse seine nets without grids. For mackerel, a 10 m^2 metal grid with 42 mm bar spacing was fitted to the seine net and for saithe a 1 × 2 m^2 glass fibre reinforced polyester grid with 30 mm bar spacing was fitted. As the nets were hauled in, fish escaping through the grids were collected in separate net pen. Across all trials, numbers of grid-escaped fish were 16,285 mackerel and 7,848 saithe. Fish that did not pass through an escape grid numbered 37,775 mackerel and 25,463 saithe. Survival was recorded weekly for a month.

A replicated study in 2003–2004 of a seabed area in the Atlantic Ocean off Portugal (3) found that fitting a large-diamond mesh escape panel to a bottom purse seine net reduced the amount of unwanted or undersized fish catch compared to standard nets. For seven of seven fish species, including five important discarded species (see paper for species), the average weight of the species that escaped through the large-mesh panel were 6–231 kg/set and average escape rates were 7–92% (three species >85%, four species <59%). There was no difference in average size between escaped fish and fish discarded in commercial deployments without large-mesh panels for four of seven species (with: 12.3–42.5 cm, without: 11.9–42.3 cm) but size was significantly lower for three species (with: 12.6–18.7 cm, without: 13.4–19.0 cm). Sampling was done from April 2003 to July 2004, in a 36 km stretch of water within 10 km of the south coast of Portugal, at depths from 10–33 m. Eight experimental deployments were done from a small charter vessel using a standard bottom purse seine net of 18 mm mesh fitted with a 70 mm panel of diamond mesh, 4 × 6 m in the rear wing (see paper for specifications). Fish escaping from the large-mesh panel were sampled in an 18 mm mesh cover. Catches from 61 commercial purse seine deployments were sampled separately for proportions of fish kept and discarded. For all deployments, total catches or a sub-sample if large amounts were caught were sorted by species, weighed and lengths recorded.

(1) Gray C.A., Larsen R.B. & Kennelly S.J. (2000) Use of transparent netting to improve size selectivity and reduce bycatch in fish seine nets. *Fisheries Research*, 45, 155–166.
(2) Misund O.A. & Beltestad A.K. (2000) Survival of mackerel and saithe that escape through sorting grids in purse seines. *Fisheries Research*, 48, 31–41.
(3) Gonçalves J.M.S., Bentes L., Monteiro P., Coelho R., Corado M. & Erzini K. (2008) Reducing discards in a demersal purse-seine fishery. *Aquatic Living Resources*, 21, 135–144.

2.40 Modify the design or configuration of trawl gear (mixed measures)

- **Nineteen studies** examined the effects of modifying the design or configuration of trawl gear on marine fish populations. Seven studies were in the Clarence River estuary[9,12,13,14,15,16,19] (Australia), three studies were in each of the Mediterranean Sea[3,5,17] (Turkey) and North Sea[2,6,11] (UK), two studies were in the North Pacific Ocean[4,10] (USA), and one study was in each of the South Pacific Ocean[1], the Skagerrak and Baltic Sea[7] (Denmark/Sweden), the Atlantic Ocean[8] (USA) and the Coral Sea[18] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (19 STUDIES)

- **Reduce unwanted catch (16 studies):** Twelve of 16 replicated studies (seven paired and controlled, five controlled, and two paired) in the Clarence River estuary[9,12,13,14,15,16,19], South Pacific Ocean[1], North Pacific Ocean[4,10], Mediterranean Sea[5,17], Skagerrak and Baltic Sea[7], Atlantic Ocean[8], North Sea[11] and the Coral Sea[18] found that various modifications to trawl gear, including changes to the trawl wires[1], number of nets[1,13], codend number[9], footrope configuration[4,10], front trawl body panels[8,11,12,15,16], codend netting layers[5], spreading mechanism[14], method of weaving[17], knot orientation[19] or using a new overall trawl design[7,18], resulted in reduced unwanted catches of non-target and/or discarded fish species or sizes[4,5,7,8,10,13,14,16,17,18,19], and of all sizes of four of seven commercial species[11], compared to standard unmodified trawl gear or other trawl designs. One of these[11] also found increased catch rate of one commercial species and for another two species the effect varied with fish size. Two studies[12,15] found that modified trawl gear reduced the unwanted catch of only a small proportion of the number of individual fish species caught compared to other trawl configurations, and also that unwanted fish catches varied between day/night[12]. One study[1] found that different trawl configurations had mixed effects on the numbers and sizes of non-target fish catch. The other study[9] found no reduction in catches of discarded finfish between a modified and standard trawl codend.

- **Improved size-selectivity of fishing gear (5 studies):** Five replicated, controlled studies in the North Sea[2,6] and Mediterranean Sea[3,5,17] found that various modifications to trawl gear, including changes to the length of the extension piece[2], the codend strengthening bag[6], the method of weaving[17], the number of codend layers[5] and overall design[3] improved the size-selectivity for unwanted (non-target/discarded) fish species or sizes[2,3,5,6,17], and annular seabream in one of two cases[3,5], compared to unmodified standard trawl gear or other design configurations.

Background

Fishing using trawls involves towing trawl gear either through the water column or along the seabed, behind one or more fishing vessels. There are many different types of trawl gear and they vary according to the species being targeted and the characteristics of the fished area. However, in general they consist of the main trawl net – made from one or more panels of netting – held open by either a metal beam (beam trawl) or solid doors (e.g. otter boards), attached to the trawl net by long wires ("sweeps" and "bridles"). Trawls often have floats attached to the rope at the top of the net opening ("headrope") to help keep the net open while fishing and, in the case of bottom trawls, solid discs ("bobbins" or "rockhoppers") along the rope at the bottom (footrope) to reduce the likelihood of the net getting caught or damaged on the seabed (Grieve *et al.* 2014). Some trawl gear may be towed as a single, double, or even triple-net configuration. Individual trawl components can be adjusted or modified to improve efficiency and catch rates of commercially targeted species. However, modifications may also reduce the catches of unwanted fish species or sizes. The evidence summarized here covers a range of potential modifications to the configuration of trawl gear or one or more of its many components (e.g. netting length, panel dimensions, footrope and bridle configurations), however, it does not include other potential modifications to the trawl net that deal specifically with reducing unwanted catch and improving size-selectivity (e.g. mesh configuration and unwanted catch reduction devices).

Evidence for interventions describing other modifications to the overall design of different types of trawl gear is summarized under '*Fishing gear modification - Change the size of the main body of a trawl net*', '*Decrease the circumference or diameter of the codend of a trawl net*', '*Modify the design or configuration of trawl doors*', '*Modify a bottom trawl to raise parts of the gear off the seabed during fishing*' and '*Modify design or arrangement of tickler chains/chain mats in a bottom trawl*'.

Grieve C., Brady D., & Polet H. (2014). Review of habitat dependent impacts of mobile and static fishing gears that interact with the sea bed. *Marine Steward Council Science Series*, 2, 18-88.

A replicated study in 1989 in an area of seabed in the South Pacific Ocean off New South Wales, Australia (1) found that modifying the configuration (wire length and single or triple trawls) of four prawn trawl nets resulted in mixed effects on the reduction of non-target catches of red spot whiting *Sillago bassensis* and sand flathead *Platycephalus caeruleopuncta*. Overall catch rates of red spot whiting and sand flathead were similar for three of the four configurations (whiting, single/7 m: 2.4, single/40 m: 3.9, triple: 4.3 fish/ha; flathead, single/7 m: 1.7, single/40 m: 3.0, triple: 2.0 fish/ha) and higher in single trawls with 140 m wires/bridles (whiting: 13.8 fish/ha, flathead: 6.1 fish/ha). However, average fish length was greater in single trawls with 140 m bridles for both species (red spot whiting: 17.9 cm, sand flathead: 33.5 cm) compared to any other single trawls (whiting: 17.3–17.4 cm, flathead: 31.9–32.5 cm) and the triple trawl (whiting: 16.6 cm, flathead: 32.4 cm). In addition, the total weight of non-target catch (fish and invertebrates combined) was not statistically different between single- and triple net trawls (single, 7 m: 15 kg/ha, 40 m: 19 kg/ha, 140 m: 23 kg/ha; triple: 13 kg/ha), as were catches of target prawns *Penaidae* and shovelnose lobster *Ibacus* spp. (see paper for data). Replicate trawl deployments (30 min, 2.8 knots) were conducted with four trawl designs (single trawls with 7 m, 40 m or 140 m bridles, or triple rigged trawls) in December 1989 in 35–40 m depth. Full details of trawl designs are provided in the original study.

A replicated, controlled study in 1986–1988 on bottom fishing grounds in the North Sea, UK (2) found that modifying the design of bottom trawls and seine nets (changing length of extension piece) resulted in an increase in size-selectivity with shorter extension pieces for haddock *Melanogrammus aeglefinus*, whiting *Merlangius merlangus* and cod *Gadus morhua*. For both gear types, extension length affected size-selectivity and increased with decreasing length (data reported as statistical results). Overall, the estimated lengths at which fish had a 50% chance of escape with the shortest extension piece (0 m) ranged from 15–32 cm for haddock, 20–35 cm for whiting and 16–36 cm for cod. For the longest extension length (13.7 m) these were decreased to 11–28 cm for haddock, 15–30 cm for whiting and 12–32 cm for cod. In addition, gear size-selectivity increased with increasing mesh size and narrower diameters of the codend, and their effect was greater than the effect of extension length. Data were collected during three surveys on two commercial vessels between 1986–1988 in the northern or central North Sea. Fishing was conducted with two seine nets and one trawl net configured with three different extension lengths (0, 9.1 and 13.7 m), mesh sizes (80, 90 and 100 mm) and codend diameters (2.2, 3.2 and 4 m). For seine nets, 114 hauls were completed with a 9.1 m extension, 104 hauls with a 13.7 m extension and 110 hauls with a 0 m extension. For the trawls, 37, 35 and 35 hauls were completed for the 9.1, 13.7 and 0 m extensions, respectively. Small mesh covers attached over the codends sampled fish escaping through the meshes. All fish in the codends and covers were identified, and length recorded. No cod were caught in trawl net deployments.

A replicated, controlled study in 1994 of an area of seabed in the Mediterranean Sea, off Turkey (3) found that two different trawl codend designs increased the size selectivity of red mullet *Mullus barbatus* compared to a standard codend, but there were no differences between codend types for annular seabream *Diplodus annularis*. The length at which red mullet had a 50% chance of escape was higher in both a 'shortened lastridge rope' codend (15.1cm) and a narrowed circumference codend (14.3 cm) compared to the standard (13.7 cm). For annular seabream, the 50% selection length was similar between all codends (short rope: 9.8 cm, narrow: 10.1 cm, standard: 9.9 cm). Data were collected in June and September 1994 in the Aegean Sea, from 40 trawl deployments (40–100 m depth, 50–60 min) of three different codend types: a roped codend rigged onto shortened ropes along each seam (14 hauls), a codend with the circumference reduced to 120 from 150 meshes (12 hauls), and a standard codend of 44 mm diamond mesh and 150 mesh circumference (see original paper for gear specifications). Small mesh covers attached over the codends sampled escaped fish. Codend and cover catches were sampled, and fish (fork) length recorded.

A replicated, paired, controlled study of an area of seabed in the Pacific Ocean off the coast of Oregon, USA (4) found that modifications to the configuration of a shrimp trawl (to alter the height of the fishing line/footrope) resulted in reduced catches of unwanted small flatfish (Pleuronectiformes) and immature rockfish *Sebastes* spp. with increasing height of the fishing line. Catches of flatfish and rockfish between trawls with the same or higher fishing line height relative to the standard, were lower for two of two modified configurations (higher: 2–64 fish, standard: 4–81 fish). Conversely, catch numbers of both flatfish and rockfish increased in two of three trawl configurations with lower fishing line heights relative to the standard height (lower: 31–147 fish, standard: 2–50 fish), but were not significantly different in the other (lower height: 4–285 fish, standard height: 5–156 fish). Data were collected from 26 paired trawl deployments on a twin-rigged (dual net) commercial shrimp vessel fishing out of Newport. One side of the trawl was fished with a 'standard' configuration in which the central 'drop' chains between the fishing line and groundline were shortened to 51 cm. Four different configurations of drop chains were tested against the standard, each either increasing or decreasing the height of the fishing line (see original paper for full gear specifications). Five sets of comparative hauls were carried out (4–6 of each comparison). Codend catches were weighed and counted by species. The study does not report when the sampling took place.

A replicated, controlled study in 2002 of seabed in a coastal bay in the Mediterranean Sea, off Turkey (5) found that modifying the design of a bottom trawl net (single or double layer codends) resulted in improved size-selectivity and reduced catches of smaller fish in single codends for red mullet *Mullus barbatus*, annular sea bream *Diplodus annularis*, and common pandora *Pagellus erythrinus*, compared to a double layer codend. The length at which fish had a 50% chance of escape was greater in single layer codends than double codends for red mullet (single: 10 cm, double: 9 cm), annular sea bream (single: 9 cm, double: 8 cm) and common pandora (single: 11, double: 8 cm). The total number of fish that escaped capture was higher with a single codend for all three species (red mullet, single: 1,928, double: 599 fish; annular sea bream, single: 304, double: 53 fish; common pandora, single: 381, double: 82 fish). In April 2002, bottom trawl deployments were carried out in Izmir Bay in the eastern Aegean Sea; nine with codends of a single layer of netting (one codend) and nine with double layer codends (one codend mounted around another, see original paper for gear specifications). Gear was towed for 45 minutes at 2.2–2.6 knots and 25–30 m depth. Codends had 200 mesh circumferences and 40 mm mesh size. Covers attached over each codend type collected escaped fish. Both codend and cover catches were sampled, and fish lengths recorded.

A replicated, controlled study in 2001 in an area of seabed in the North Sea, off the Orkney Islands, UK (6) found that modifying a bottom trawl by removing the strengthening bag (a large-mesh cover to prevent the codend from splitting when catch is heavy) improved the size-selectivity of haddock *Melanogrammus aeglefinus* at two mesh sizes. The length at which haddock had a 50% chance of escape was higher without a strengthening bag at both 110 mm codend mesh size (without: 31.4 cm, with: 31.4 cm) and 120 mm mesh codend (without: 34.3 cm, with: 32.4 cm). A total of 26 trawl deployments were completed on a commercial fishing vessel in June 2001: seven each with a 110 mm codend, with and without a strengthening bag, and six each with a 120 mm codend, with and without a strengthening bag (all diamond mesh). Hauls were 120–198 minutes at 68–87 m depth. The strengthening bag used 265 mm diamond mesh and 6 mm diameter twine (see original paper for full gear specifications). A cover attached over the codends sampled fish that escaped through the meshes. Codend and cover catches were sampled, and fish lengths recorded.

A replicated, controlled study in 1996–1997 in two areas of seabed in the Skagerrak and Baltic Sea around Scandinavia (7) found that modifying the design of a flatfish trawl reduced the unwanted catch of Atlantic cod *Gadus morhua*, compared to a standard design. Across all trails, total catch numbers of all cod and undersized (<40 cm) cod were reduced in the modified trawl design compared to conventional trawls, by 15–75% in four of four cases, and by 50–80% in three of four cases (the fourth case showed an increase of 24%), respectively. In addition, there were no differences in catch numbers of undersized individuals of the target flatfish species plaice *Pleuronectes platessa* and flounder *Platichthys flesus*. However, catches above the minimum landing sizes were higher in modified trawls in one of one plaice (>27 cm: 15%) and one of three flounder (>25 cm: 46%) comparisons. Experimental trials were carried out in June 1996 in the Skagerrak and the North Sea and in December 1996 and January 1997 in the Baltic Sea. Trials compared two modified trawl designs to conventional trawls targeting plaice (Skagerrak/North Sea) and flounder (Baltic Sea). Modifications included a triangle of large mesh (400 mm) at the trawl opening, reduced flotation to keep a low vertical opening, a long headline to increase the seabed area swept by the trawl, and different configurations of square mesh panels/windows (see original paper for full gear specifications).

A replicated, paired, controlled study in 2005–2006 in an area of seabed in the northwest Atlantic Ocean, USA (8) found that using a modified design of bottom fish trawl (large mesh in the front sections) reduced the catches of most non-target fish species, compared to a conventional trawl. Total catch weights were lower in the modified trawl compared to the conventional trawl for 15 of 19 non-target fish species, including cod *Gadus morhua* (the main unwanted species) and several other commercial bottom species with stock levels of concern (see original paper for species individual data). Total catch weights of haddock *Melanogrammus aeglefinus* (the target species) were similar between trawl types (modified: 12,580, standard: 14,327 kg), and the ratio of haddock by weight to that of four key non-target fish species was increased in modified trawls from less <1 haddock/non-target species to 151 haddock/non-target species. Data were collected from 100 parallel trawl deployments on two vessels during four fishing trials from June 2005 to April 2006, in and around a closed area on the Georges Bank (37–154 m depth). Vessels towed side-by-side, one using a modified trawl design constructed with large mesh (240 cm) front sections (‘Eliminator Trawl™’), and the other a conventional trawl. Full details of the trawl designs are provided in the original study.

A replicated, controlled study in 2007 of an area of seabed in an estuary flowing into the Tasman Sea, Australia (9) found that modifying a prawn trawl by separating the codend into two compartments (double codend) did not reduce the catches of discarded finfish, compared to a conventional single codend. Average catch weights of discarded finfish species were similar for double and single codend trawls (double: 0.9 kg, single: 1.0 kg). In addition, average retained and discarded weights of the target school prawn *Metapenaeus macleayi* were both similar between codend types (double: 0.7–9.3 kg, single: 0.8–9.5 kg). In October 2007, a total of 24 trawl deployments (1 h) were done on a prawn fishing ground in Lake Wooloweyah, Clarence River estuary, New South Wales. Two codend types were tested: one modified with two compartments (12 hauls), and one with a single codend (12 hauls). Both codend types were square mesh (27 mm) and had a size-sorting escape grid (see original paper for gear specifications).

A replicated, paired, controlled study in 2010 in an area of seabed in the North Pacific Ocean, off Oregon, USA (10) found that modifications to the footrope of prawn trawl gear reduced the capture of unwanted eulachon *Thaleichthys pacificus*, and other unwanted finfish species, compared to a conventional trawl design. The average weight of unwanted catch was reduced in the modified trawl compared to the conventional trawl, by 34% for eulachon (modified: 1,891, standard: 2,858 g/haul), by 96% for slender sole *Lyopsetta exilis* (modified: <1, standard: 4 kg/haul), by 97% for other small flatfish (modified: <1, standard: 2 kg/haul) and by 80% for darkblotched rockfish *Sebastes crameri* (modified: 13, standard: 61 g/haul). However, there were no differences between gear types for whitebait smelt *Allosmerus elongatus* (modified: 18, standard: 29 g/haul) and Pacific herring *Clupea pallasii* (modified: 1, standard: 1 kg/haul). In addition, target ocean shrimp *Pandalus jordani* catches were not statistically different between gear types (see paper for data). Experimental trials were conducted from 26 paired deployments on a double-rigged shrimp trawler in June 2010 (99–148 m depth, 1.6–1.8 knots, 45–60 min). Two trawl types were tested simultaneously: a modified trawl with the central section of the groundline removed and drop chains attached to the central section to help stabilise it, and a standard trawl with a complete groundline (see original paper for gear specifications). Both trawl types had a rigid size-sorting escape grid (19 mm bar spacing).

A replicated, paired, controlled study in 2009 of two areas of seabed in the North Sea off the Shetland Islands, UK (11) found that modifying the forward sections of a bottom trawl net (increases in mesh sizes) resulted in reduced catch rates of all sizes of four of seven commercial fish species, increased catch rates of one species in one of two cases, and for the other two species the effect varied with fish size, compared to standard forward sections. Overall, increased mesh sizes of 300 mm and 600 mm caught fewer Atlantic cod *Gadus morhua (*by 49% and 75%), megrim *Lepidorhombus whiffiagonis* (by 79% and 93%), ling *Molva* molva (by 36% and 68%) and hake *Merluccius merluccius* (by 28% and 53%) at all lengths, relative to standard mesh sizes of the forward sections (120/160 mm). Relative catch of haddock *Melanogrammus aeglefinus* was similar with the 600 mm gear (5% difference) but higher by 42% with the 300 mm gear compared to the standard. The 300 mm and 600 mm gears caught fewer monkfish *Lophius piscatorius* below 76 cm and 83 cm respectively (and similar catch of fish above these sizes) and saithe *Pollachius virens* above 53 cm (data reported as statistical results). Trials were conducted on two Shetland fishing grounds 30 nautical miles apart (104–150 m and 163–185 m depths), by a twin-rig trawler in June and July 2009. The 600 mm mesh was deployed only in one area (14 hauls) and the 300 mesh was trialled in both areas (30 hauls in total). Both modified trawl types were fished alongside a standard bottom trawl (see original paper for gear specifications).

A replicated, paired study in 2011–2012 of sandy mud bottom in an river/estuary flowing into the Tasman Sea, Australia (12) found that modifying the length and number of panels in the body of a prawn trawl net reduced the unwanted catch of one of four main fish species caught in shorter compared to longer trawls. Average catch rates of southern herring *Herklotsichthys castelnaui* were lower in shorter trawl designs than longer designs (short: 4 fish/ha, long: 1–2 fish/ha), irrespective of panel number. But there were no differences between trawl types for Ramsey's perchlet *Ambassis marianus*, narrow banded sole *Synclidopus macleayanus* or yellowfin bream *Acanthopagrus australis* (short: 1–7 fish/ha, long: 1–6 fish/ha). Numbers of target school prawns *Metapenaeus macleayi* were lower in shorter trawls (short: 1,107 ind/ha, long: 2,247 ind/ha). Sampling was conducted in December 2011 and January 2012 in the Clarence River, New South Wales, using a local prawn trawler. Four designs of trawl were tested (see original paper for gear specifications). All were identical except for their body length/side taper (short 35°, or long 25°) and the number of panels (two or four). Twenty paired deployments with each trawl design were completed. Codend catches were sorted and weighed by species. Data on the main target and non-target species were analysed.

A replicated study in 2012 of sandy mud bottom in an estuary flowing into the Tasman Sea, Australia (13) found that changes to the configuration (number of nets, one to four) of prawn trawl gear resulted in lower overall catches of non-target fish species in triple trawls, and fewer of one of six of the main non-target individual fish species in multi-rigged trawls compared to a single trawl net. Average weight, but not number, of all non-target catch (more than 95% of which was just six fish species) differed between trawl configurations and was lower only in triple-rigged trawls (0.5 kg/ha) compared to single-rigged trawls (1.0 kg/ha), but similar for all other comparisons between trawl types (double-rigged: 0.7 kg/ha, quadruple-rigged: 0.7 kg/ha). Individually for the main six fish species caught, the catch rate of only yellowfin bream *Acanthopagurus australis* differed between trawl designs and was lower in double-rigged, triple-rigged and quadruple-rigged (2 ind/ha) trawls than in single trawls (4 ind/ha). But there were no differences between trawl designs in the catch rates of five other unwanted fish species, fork-tail catfish *Arius graeffei*, narrow-banded sole *Synclidopus macleayanus*, bullrout *Notesthes robusta*, silver biddy *Gerres subfasciatus* and mulloway *Argyrosomus japonicus* (see original paper for species individual data by gear type). Catch rates of the target school prawn *Metapenaeus macleayi* were similar across trawl configurations, (single: 600, double: 750, triple: 900, quadruple: 1,450 ind/ha), although single-rigged trawls retained larger individuals. In March and May 2012, a total of 36 experimental deployments/trawl configuration were made in the Clarence River estuary (3–18 m depth) of four trawl configurations: single, double, triple or quadruple-rigged. All used 45 mm mesh, but each configuration had different technical specifications (see original paper for details).

A replicated, controlled study in 2013 of an area of sand and mud bottom in an estuary off the Tasman Sea, Australia (14) found that modifying the configuration (spreading mechanism) of prawn trawls resulted in reduced overall catches of unwanted fish in one of four configurations. Average catch rate of unwanted fish by number was lower in otter trawls without sweep wires (62 fish/40 min) than with (96 fish/40 min), and was similar to beam trawls both with and without a horizontal wire across the trawl mouth (with: 59 fish/40 min, without: 73 fish/40 min). Catches of target school prawn *Metapenaeus macleayi* were similar in otter trawls with and without sweep wires (with: 2,600, without: 2,100 ind/40 min), but lower in beam trawls with a horizontal wire (1,200 ind/40 min) than without (1,600 ind/40 min). In summer (austral) 2013, a total of 36 trawl deployments in Lake Wooloweyah estuary in New South Wales (at 1–2 m depth) were done with each of four trawl designs: an otter trawl, with and without sweep bridles, and a beam trawl with and without a horizontal wire. Sweep wires were removed to test reduction in the herding of fish into the net and the horizontal wire was designed to produce a fish escape response. Full details of the trawl specifications are provided in the original study.

A replicated, paired study in 2014 of an area of shallow sandy mud bottom in an estuary lagoon site in off the Tasman Sea, Australia (15) found that modifying the design of prawn trawls (body length/side taper) reduced the unwanted catch of only one of seven main fish species caught, and for most of the rest, catches varied with light conditions (day/night). Catch rate of only one of seven unwanted fish species, Australian anchovy *Engraulis australis*, was lower in a short trawl (0–2 fish/ha) than a long trawl (1–3 fish/ha), irrespective of day or night sampling times, and southern herring

Herklotsichthys castelnaui catch rate was lower in the short trawl during daylight only (short: 48 fish/ha, long: 68 fish/ha). However, regardless of trawl type, catch rates of forktail catfish *Arius graeffei*, pinkbreast siphonfish *Siphamia roseigaster*, and yellowfin bream *Acanthopagrus australis*, were lower during the day than night, whereas whitebait *Hyperlophus vittatus* catches were lower during the night. Neither trawl type nor sampling time affected catch rates of Ramsey's perchlet *Ambassis marianus* (see original paper for species individual data by trawl type/sampling time). In addition, the catch rates (weight and numbers) of the target species school prawns *Metapenaeus macleayi* were lower in the short trawl than the long trawl (short: 7 kg/ha, long: 9 kg/ha). In March and April 2014, a total of 44 paired deployments (45 min) were made in Lake Wooloweyah, Clarence River estuary, New South Wales, with one short and one long prawn trawl, during six days and four nights. Trawls nets were identical apart from different configurations of wing and body tapers (see original paper for gear specifications).

A replicated, paired, controlled study in 2013–2014 of an area of sand and mud bottom in the Clarence River estuary, Tasman Sea, Australia (16) found that modifying a prawn trawl design (wing mesh orientation and hanging ratio) typically reduced the overall catches of unwanted fish by number, but not by weight, compared to a conventional design. Overall catch numbers of unwanted fish were reduced in three of the four modified trawls compared to the conventional trawl (diamond mesh wings, both loose and tight: 35 fish/ha, loose square mesh: 37 fish/ha, conventional: 55 fish/ha), but were similar in the tight square mesh trawl (40 fish/ha). By weight, catch rate of all non-target fish species was reduced only with loose diamond wings (0.7 kg/ha) compared to the conventional trawl (1.1 kg/ha), and was similar between the other three designs and the conventional trawl (0.8 kg/ha). In (austral) summer 2013/2014, four novel trawl configurations (35 mm diamond or square mesh wing/side panels, and loose or tight hanging ratios) were tested against a conventional trawl with 41 mm diamond mesh wings. Twenty-four deployments of each trawl design were conducted on a twin-rigged trawler, paired with another design. All trawls also had a size-sorting escape grid. Full trawl details are provided in the original paper.

A replicated, controlled study in 2011 of a fished area of seabed in the Mediterranean Sea, Turkey (17) found that three different designs of bottom trawl codend woven by machine instead of by hand, improved size-selectivity and reduced the discarded catches of five commercial fish species compared to a commonly used commercial hand-woven codend. The length at which fish had a 50% chance of escaping was higher in machine-woven codends than hand-woven codends for: red mullet *Mullus barbatus* (machine: 8–14 cm, hand: 7 cm); brushtooth lizardfish *Saurida undosquamis* (machine: 23–28 cm, hand: 8 cm); common pandora *Pagellus erythrinus* (machine: 12–15 cm, hand: 8 cm); goldband goatfish *Upeneus moluccensis* (machine: 12–21 cm, hand: 5 cm); and Randall's threadfin bream *Nemipterus randalli* (machine: 10–14 cm, hand: 6 cm). In addition, the proportions of undersized fish retained for the five species were lower in machine codends compared to the hand codend design, however, there were also increased losses of commercial sizes for some species (see original paper for full data by species). Trials were done with three alternative machine-woven trawl codends (40 mm square mesh; 44 mm and 50 mm diamond mesh) and a commercial hand-woven codend (44 mm diamond mesh) on fishing grounds in Mersin Bay between January-December 2011. Data were collected from a total of 87 individual deployments (20–23 of each of the four codends) onboard a commercial trawler. Tow duration was 80–220 minutes at a speed of

2.3–2.8 knots. A small-mesh cover was fitted over each codend to collect the escaped fish. Catches in the codends and covers were sampled.

A replicated, paired, controlled study in 2014 of a fished area of seabed in Moreton Bay in the Coral Sea, Australia (18) found that using a different design of prawn trawl (a 'W-trawl') reduced the quantities of unwanted fish in one of four cases, compared to a conventional trawl design. The catch rates of unwanted fish were lower in the first of four designs of W-trawl configuration compared to the conventional trawl (original: 5 kg/ha: conventional: 2 kg/ha). However, there were no differences in catch rates of unwanted fish between three subsequent modifications to the original W-trawl design and the conventional design (modified: 1–2 kg/ha, conventional: 2–3 kg/ha). In addition, target shrimp *Penaeidae* catches were reduced in all W-trawl designs compared to the conventional, by 27–80%. Trials were carried out by a double-rigged commercial vessel on trawl fishing grounds in Moreton Bay in February 2014. One of four designs of W-trawl were deployed in paired tows with a conventional trawl design (Florida Flyer). A total of 45 paired deployments were made (10 to 13 of each W-trawl design) and all trawls had a 42 mm diamond mesh codend (see original paper for gear specifications).

A replicated, paired, controlled study (year not provided) of sand and mud bottom in an estuary off the Tasman Sea, New South Wales, Australia (19) found that modifying a prawn trawl net (knot orientation) reduced the catches of unwanted fish species compared to a conventional trawl. Overall catch rate of unwanted fish species was lower in a modified trawl with a negative knot angle of attack than the conventional positive attack angle (modified: 90 fish/ha, conventional: 110 fish/ha). For the five most abundant non-target fish species caught, individual catch rates were lower with negative angles of attack for three: yellowfin bream *Acanthopagrus australis* (modified: 4, conventional: 8 fish/ha), southern herring *Herklotsichthys castelnaui* (modified: 2, conventional: 8 fish/ha) and silver biddy *Gerres subfasciatus* (modified: 0.2, conventional: 1.3 fish/ha); but similar for forktail catfish *Arius graeffei* (modified: 80, conventional: 88 fish/ha) and Ramsey's perchlet *Ambassis marianus* (modified: 0.4, conventional: 0.7 fish/ha). Target school prawn *Metepenaeus macleayi* catches were also lower with the modified knot orientation (modified: 675, conventional: 775 ind/ha). Fishing trials were done in the austral summer in the Clarence River estuary (2–20 m depth) using a local trawler. Knot-force direction in the top and bottom net panels was compared by turning a conventional trawl with a positive angle of attack inside out to create a negative angle of attack (see original paper for full gear specifications). A total of 24 paired deployments (45 min) of both trawl types were completed. The authors reported that altering the knot orientation may have affected the overall geometry of the trawl during fishing (e.g. a lower position in the water column and lower headline height).

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(10) Hannah R.W., Jones S., Lomeli M.J.M. & Wakefield W.W. (2011) Trawl net modifications to reduce the bycatch of eulachon (*Thaleichthys pacificus*) in the ocean shrimp (*Pandalus jordani*) fishery. *Fisheries Research*, 110, 277–282.
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(12) Broadhurst M.K, Sterling D.J. & Millar R.B. (2012) Short vs long penaeid trawls: Effects of side taper on engineering and catching performances. *Fisheries Research*, 134–136, 73–81.
(13) Broadhurst M.K., Sterling D.J., & Millar R.B. (2013) Progressing more environmentally benign penaeid-trawling systems by comparing Australian single-and multi-net configurations. *Fisheries Research*, 146, 7–17.
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(15) Broadhurst M.K., Sterling D.J. & Millar R.B. (2015) Effects of diel period and diurnal cloud cover on the species selection of short and long penaeid trawls. *Fisheries Research*, 170, 144–151.
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(17) Özbilgin H., Eryaşar A.R., Gökçe G., Özgilbin Y.D., Bozaoğlu A.S., Kalecik E & Herrmann B. (2015) Size selectivity of hand and machine woven codends and short-term commercial loss in the Northeastern Mediterranean. *Fisheries Research*, 164, 73–85.
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2.41 Change the size of the main body of a trawl net

- **One study** examined the effects of changing the size of the main body of a trawl net to reduce unwanted catch on marine fish populations. The study was in the North Sea[1] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Improved size-selectivity of fishing gear (1 study):** One replicated study in the North Sea[1] found that reducing the size of the main body of a trawl net did not improve the size-selection of cod and haddock.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Fish entering the net will either be retained by it or may escape through the gaps in the mesh of the trawl netting during fishing. Many factors can influence the likelihood of a fish being caught or escaping from a trawl (termed selectivity or efficiency) including species, size of fish, time of day, and trawl configuration. One factor that may affect selectivity is gear size. Fish behaviour can differ on encountering different trawl nets (Krag *et al*. 2014) and changing the size of trawl gear alters the overall dimensions (such as the width and height at the trawl mouth) and can subsequently affect the numbers of fish able to avoid it. Fish have been observed to actively escape trawl nets by accelerated swimming in bursts or changing direction, or, more commonly, escaping in response to contact with the net (Jones *et al.* 2008).

For related interventions describing other modifications to the overall design of different types or parts of trawl gear is summarized under '*Fishing gear modification - Modify the design or configuration of trawl gear (mixed measures)*', *'Decrease the circumference or diameter of the codend of a trawl net'*, *'Modify the design or configuration of trawl doors'*, *'Modify a bottom trawl to raise parts of the gear off the seabed during fishing'* and *'Modify design or arrangement of tickler chains/chain mats in a bottom trawl'*.

Krag L. A., Herrmann B. & Karlsen J. D. (2014) Inferring Fish Escape Behaviour in Trawls Based on Catch Comparison Data: Model Development and Evaluation Based on Data from Skagerrak, Denmark. *PLoS ONE*, 9, e88819.

Jones E., Summerbell K. & O'Neill F. (2008) The influence of towing speed and fish density on the behaviour of haddock in a trawl cod-end. *Fisheries Research,* 98, 166–174.

A replicated study in 1997 of an area of seabed in the North Sea off southern Norway (1) found that reducing the size of a trawl net body did not affect the size-selectivity of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* compared to a larger trawl body. The length at which fish had a 50% chance of escaping was similar between two trawl body sizes for both cod (small: 32.8 cm, large: 31.8 cm) and haddock (small: 27.0 cm, large: 27.1 cm). In addition, the size-selection ranges of retained fish of both species were similar between trawl sizes (small: 4.4–8.2 cm, large: 4.9–7.7 cm). In March/April 1997, two bottom trawl nets, one small ('minihopper') and one larger ('codhopper'), of different body dimensions but identical codends, were tested in 23 trawl deployments by a research fishing vessel (see paper for specifications). The small trawl was a specially designed version of a larger trawl which was commonly used for stock assessments. Average measurements for the small trawl were 3.3 m (height) and 20.7 m (spread) and for the larger trawl 3.7 m (height) and 24.9 m (spread). Covers attached to the codend collected fish escaping through the net. All codend and cover catches were sorted and weighed by species and total lengths recorded.

(1) Dahm E., Wienbeck H., West C.W., Valdemarsen J.W. & O'Neill F.G. (2002) On the influence of towing speed and gear size on the selective properties of bottom trawls. *Fisheries Research*, 55, 103–119.

2.42 Decrease the circumference or diameter of the codend of a trawl net

- **Thirteen studies** examined the effects of decreasing the circumference or diameter of a trawl codend on marine fish populations. Four studies were in the Tasman Sea[3,4,6,7] (Australia) and three studies were in the North Sea[1,2,5] (UK, Norway). Two studies were in the Adriatic Sea[8,9] (Italy) and two were in the Baltic Sea[10,11] (Denmark/ Germany). One study and one review were in the Northeast Atlantic Ocean[12,13] (Northern Europe).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (13 STUDIES)

- **Reduction of unwanted catch (6 studies):** Two of six replicated, controlled studies (three paired, and one randomized and paired) in the Tasman Sea[3,4,6,7], Adriatic Sea[8] and Northeast Atlantic Ocean[13] found that bottom trawl nets of smaller circumferences reduced discarded catch of fish in three of five cases[3] and of total discarded catch (fish and invertebrates) in one of two areas, but not overall[13], compared to standard trawls. Two studies found that reduced circumference codends reduced non-target or discarded fish catch in three of 12 cases[4] and for one of four species[6]. The two other studies[7,8] found that discarded fish catch was not reduced in smaller circumference codends.
- **Improve size-selectivity of fishing gear (8 studies):** Four of eight replicated, controlled studies (one paired) in the North Sea[1,2,5], Adriatic Sea[8,9] and Baltic Sea[10,11], and one review in the Northeast Atlantic Ocean[12], found that decreasing the circumference or diameter of the codend of trawl gear (bottom trawls and seines) improved the size-selectivity of haddock[1,2,12], Atlantic cod[1,2,10], whiting[1,2] and European hake and red mullet[9], compared to larger circumferences/diameters. One[9] also found the effect was the same across two codend mesh sizes, and one[10] also found the effect was greater in diamond mesh with the netting orientation turned by 90° compared to standard diamond mesh. Two studies[5,11] found that a decrease in codend circumference/diameter improved size-selectivity of haddock and saithe[5] in one of two cases, and of one of three fish species[11]. The other study[8] found that a smaller circumference codend reduced size-selectivity of the gear for one of three fish species and was similar for the other two.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl/seine) through the water behind one or more vessels. In many fisheries, particularly edible crustacean fisheries (e.g. prawns), trawls often retain unwanted small non-target or non-commercial fish species. Behavioural differences between species can be exploited to reduce the amount of unwanted catch retained in a trawl net. In trawl nets with a smaller circumference, the lateral openings of the netting mesh are larger than in larger circumference trawls, which allows more fish to pass through the netting (Armstrong *et al.* 1990). This may be due to different hydrodynamic pressures in the codend, which may stimulate a behavioural response in fish and contribute to their escape, which may not occur in crustaceans and other groups of species (Broadhurst & Kennelly 1996).

Related interventions describing other modifications to the overall design of different types or parts of trawl gear are summarized under *'Fishing gear modification - Modify the design or configuration of trawl gear (mixed measures)', 'Change the size of the main body of a trawl net', 'Modify the design or configuration of trawl doors', 'Modify a bottom trawl to raise parts of the gear off the seabed during fishing'* and *'Modify design or arrangement of tickler chains/chain mats in a bottom trawl'*.

Armstrong D.W., Ferro R.S.T., MacLennan D.N. & Reeves S.A. (1990) Gear selectivity and the conservation of fish. *Journal of fish Biology*, 37, 261–262.

Broadhurst M.K. & Kennelly S.J. (1996) Effects of the circumference of codends and a new design of square-mesh panel in reducing unwanted by-catch in the New South Wales oceanic prawn-trawl fishery, Australia. *Fisheries Research*, 27, 203–214.

A replicated, controlled study in 1986–1988 on bottom fishing grounds in the northern and central North Sea, UK (1) found that fishing nets (trawls and seines) with a narrower codend diameter improved the size-selectivity of haddock *Melanogrammus aeglefinus*, cod *Gadus morhua* and whiting *Merlangius merlangus* compared to standard and wide diameter codends. Across three codend mesh sizes and lengths of the extension piece, the length at which fish had a 50% chance of escape was greater for narrow (2.2 m) diameter codends for haddock (18–32 cm), cod (20–36 cm) and whiting (21–39 cm), compared to standard (3.2 m) codend diameters (haddock: 14–28 cm, whiting: 18–35 cm, cod: 16–32 cm) and wide (4 m) codend diameters (haddock: 11–25, whiting: 15–28, cod: 12–28 cm). Data were collected during three surveys on two commercial vessels in 1986–1988: two deploying a seine net and one a bottom trawl. Deployments were made with codends of three nominal diameters: narrow, 2.2 m (seine: 107, trawl: 36 hauls), standard, 3.2 m (seine: 105, trawl: 35 hauls) and wide, 4 m (seine: 116, trawl: 36 hauls); three mesh sizes (nominal 80, 90 and 100 mm) and three extension piece lengths (nominal 0.1, 9.1 and 13.7 m). Covers over each codend retained the fish escaping through the meshes for sampling.

A replicated, controlled study in 1991 of an area of seabed in the North Sea off Scotland, UK (2) found that bottom trawl nets of smaller codend diameter improved the size selectivity of haddock *Melanogrammus aeglefinus,* whiting *Merlangius merlangus* and cod *Gadus morhua* compared to standard and wider diameters. Across three codend mesh sizes, the length at which fish had a 50% of escape increased with decreasing codend diameter for haddock (small: 30–40 cm, standard: 25–35 cm, wide: 20–30 cm), whiting (small: 36–46 cm, standard: 29–40 cm, wide: 23–33 cm) and cod (small: 35–43 cm, standard: 29–37 cm, wide: 23–32 cm). Data were collected in August 1991 from 40 trawl deployments using nine test codends by two commercial Scottish demersal pair trawlers. Combinations of three nominal codend diameters (2.2 m, 3.2 m and 4.2 m) and three nominal codend mesh sizes (90 mm, 100 mm and 110 mm) were tested with at least four hauls/combination. Codend covers of smaller mesh size retained escaping fish catch.

A replicated, paired, controlled study in 1995 of an area of seabed in the Tasman Sea off New South Wales, Australia (3) found that decreasing the codend circumference in prawn trawl nets reduced the discarded catch of commercial and non-commercial small fish in three of five cases compared to a larger standard circumference codend. In codends of standard diamond mesh, average catch numbers of discarded fish were lower in small circumference codends compared to larger for two of two species: stout whiting *Sillago robusta* (small: 600 fish/haul, large: 1,800 fish/haul) and long-spined flathead *Platycephalus longispinis* (small: 500 fish/haul, large: 1,800 fish/haul). In diamond mesh codends fitted with square mesh panels, average number of discarded fish was lower with the smaller circumference for one of three species, stout whiting (small: 300 fish/haul, large: 800 fish/haul), and similar for long-spined flathead (small: 400 fish/haul, large: 700 fish/haul) and red spot whiting (small: 70 fish/haul, large: 60 fish/haul). In addition, commercial target king prawn *Penaeus plebejus* average catch weights were similar between codend circumferences (both 5–7 kg/haul). Data were collected in March 1995 on commercial prawn-trawl grounds using a commercial trawler fishing with a triple rigged net. Four codends were tested in pairs using the outer two nets (number of deployments not reported): 100 mesh and 200 mesh (standard) circumference, each set with without square mesh panels (see original paper for gear specifications). After each tow codend catches were sorted separately and the numbers and weights of commercial and non-commercial retained and discarded species recorded.

A replicated, randomized, paired, controlled study in 2002 in an area of seabed in an estuary leading to the Tasman Sea off New South Wales, Australia (4) found that prawn trawl codends of smaller circumference (two types) reduced the unwanted catch of six fish species in only three of 12 cases compared to a larger circumference. In diamond mesh codends, average number of unwanted fish catch was lower with a smaller circumference than a larger for three of six species (small: 18–25 fish/haul, large: 45–75 fish/haul) and similar for three (small: 2–6 fish/haul, large: 2–8 fish/haul). In square mesh codends, there were no differences in average catch numbers of the six species between a smaller circumference of tapered design and a larger, non-tapered, codend (small, tapered: 0–9 fish/haul, large, non-tapered: 0–8 fish/haul). See original paper for data by individual species. In addition, the square mesh codends caught lower average numbers of unwanted fish for four of the six species. Data were collected on a commercial prawn *Penaeidae* trawler using a twin-net configuration on commercial grounds in Lake Woolooweyah in the Clarence Estuary in March 2002. Combinations of four experimental trawl nets codends (see original paper for gear specifications), with size-sorting escape grids (Nørdmore type, 20 mm bar spacing) were tested in pairs, one either side of the vessel: two 40 mm diamond mesh codends of either 100 or 200 meshes (standard) circumference, and two square mesh codends (one tapered from 82 to 54 meshes, and one 110 mesh non-tapered). All catch in each codend was sorted and counted by species.

A replicated, paired, controlled study in 2002 of an area of fished seabed in the northern North Sea off Norway (5) found that decreasing the codend circumference of a bottom fish trawl improved the size-selectivity of haddock *Melanogrammus aeglefinus*, and for saithe *Pollachius virens* in one of two cases, compared to a standard larger circumference. For haddock, the length at which fish had a 50% chance of escape was greater for both small (60 meshes) and intermediate (80 meshes) circumferences compared to the larger standard 100 meshes (small: 37–45 cm, intermediate: 33–45 cm, standard: 27–40 cm). For saithe, the length at which fish had a 50% escape likelihood was higher (41–65 cm) in the small 60 mesh circumference codend compared to the standard 100 mesh codend (40–77 cm), but the 80 mesh codend did not differ from either (40–49 cm). Data were collected from 22 paired deployments on a twin-rig trawler in August–September 2002. Diamond mesh (120 mm nominal size) codends of three circumferences (60 meshes, 80 meshes and standard 100 meshes) were tested each deployed alongside a small mesh (50 mm) trawl to measure size-selectivity. After each haul haddock and saithe number and length from each codend were recorded, and randomly sub-sampled when catches were high.

A replicated, paired, controlled study in 2007 of an area of seabed in an estuary leading to the Tasman Sea off New South Wales, Australia (6) found that using square mesh codends of smaller circumferences in prawn trawls resulted in lower catches of one of four non-target fish compared to larger circumferences. Average catch numbers of unwanted pink-breasted siphonfish *Siphamia roseigaster* decreased with decreasing codend circumference (small: 8 fish/haul, intermediate: 20 fish/haul, large: 25 fish/haul). However, for three other unwanted fish species (silver biddy *Gerres subfasciatus*, southern herring *Herklotsichthys castelnaui* and Ramsey's perchlet *Ambassis marianus* – see original paper for species individual data) there were no statistical differences in average catch rates between codend circumferences (small: 7–25 fish/haul, intermediate: 4–18 fish/haul, large: 5–9 fish/haul). Average catch weights of all commercial target prawns *Penaeidae* were similar across codend designs (all 5 kg/haul). Experimental fishing was done in October and November 2007 on commercial prawn trawl grounds in Lake Wooloweyah on the Clarence River estuary using a local twin-rigged trawler. Three square mesh codends (27 mm nominal mesh) of varying circumference (standard 90 meshes, 150 meshes and 200 meshes) were deployed simultaneously with a small mesh (9 mm) codend, 18 deployments for each paired comparison. After each tow, codend catches were separated by species and numbers or weights recorded.

A replicated, paired, controlled study in 2005 of an area of seabed in the Tasman Sea, Australia (7) found that a smaller codend circumference in fish trawl nets did not reduce the discarded catch of five of five non-target fish species, or total discarded catch (fish and invertebrates). For five of five fish species (see original paper for species individual data), average catch numbers discarded were similar between small and large codend circumferences (small: 2–284 fish/haul, large: 54–502 fish/haul). The numbers (small: 753 fish/haul, large: 1,224–1,257 fish/haul) and weight (small: 104 kg/haul, large: 112–128 kg/haul) of total discarded catch (all fish and invertebrates) were also similar between codend circumferences. In addition, the number (small: 305 fish/haul, large: 685–1,468 fish/haul), but not weight (small: 94 kg/haul, large: 156–158 kg/haul) of commercial retained catch (fish and invertebrates) was lower in the smaller codend compared to the larger. Between March and November 2005, gears trials were done in a south-eastern Australian trawl fishery targeting school whiting *Sillago flindersi*. Three test codends, one 100 mesh and two 200 mesh circumferences, were tested in pairs during alternate deployments (16 paired deployments each) with a small mesh (40 mm) codend of 450 mesh circumference (see original paper for full specifications). Catches were counted and weighed by species and the lengths of the most abundant fish measured. Commercial species were divided into retained and discarded categories.

A replicated, controlled study in 2005 in an area of mud seabed in the Adriatic Sea off Italy (8, same experimental set-up as 9) found that using a diamond mesh bottom trawl codend of standard circumference had reduced size-selectivity for one of three non-target fish species, and did not increase escape, compared to a larger circumference diamond mesh codend, however a change in mesh configuration (to square) did improve fish size-selectivity, irrespective of codend circumference. For diamond mesh codends, the predicted length at which fish had a 50% chance of escape was similar for a standard mesh circumference compared to a larger circumference for blue whiting *Micromesistius poutassou* (standard: 10.6 cm, large: 10.6 cm) and poor cod Trisopterus minutus (standard: 6.3 cm, large: 6.3 cm), but lower for European hake *Merluccius merluccius* (standard: 8.7 cm, large: 10.1 cm). However, escape of all three species was not affected by diamond mesh codend circumference (data reported as statistical results). A codend of square mesh with similar or larger circumference as the diamond mesh codends, resulted in greater 50% escape lengths for all three species compared to the diamond mesh codends (blue whiting: 13.6 cm, poor cod: 9.2 cm, hake: 12.6 cm). Gear trials were done on a research vessel in May and September 2005 in the Western Pomo pit area (a Norway lobster *Nephrops norvegicus* fishing ground, 210 m depth). Two diamond mesh codends (standard 280 and larger 326 mesh circumference) and one square mesh codend (70 meshes) were tested during 19, 13 and 20 deployments, respectively. All codends had a nominal 40 mm mesh size (see original paper for full gear specifications). Covers over each codend collected catch escaping from the meshes. All catch was weighed by species, and fish lengths recorded.

A replicated, controlled study in 2005 in two areas of seabed in the Adriatic Sea off Italy (9, same experimental set-up as 8) found that diamond mesh bottom trawls with a smaller circumference codend had improved size-selectivity for European hake *Merluccius merluccius* and red mullet *Mullus barbatus* compared to a larger codend circumference, across two codend mesh sizes. For 56 mm mesh codends, the length at which fish had a 50% chance of escape was greater with a small (240 mesh) circumference codend than a larger (280 mesh) circumference for hake (small: 16.3 cm, large: 12.0 cm) and mullet (small: 12.8 cm, large: 10 cm). Similarly, for a 48 mm codend mesh size, the 50% escape length was greater with a small (280 mesh) circumference compared to a large (326 mesh) circumference (hake, small: 11.5 cm, large: 10.4 cm; mullet, small: 10.7 cm, large: 7.5 cm). In addition, an increase in mesh size alone resulted in an increase in size selectivity for both species. Gear trials (68 trawl deployments of 1 h duration) were carried out by research vessel in May and September 2005 on two fishing grounds (one 15–20 m depth, one 180–200 m depth) in the Central Adriatic. Four codends were tested combining small (240 and 280 meshes) or large (280 and 326 meshes) circumferences (or codend rigging ratio) with large (56 mm nominal) or small (48 mm nominal) mesh sizes (see original paper for full gear specifications). Small mesh (20 mm) covers over each codend collected catch escaping through the meshes. All catch was weighed by species, and fish lengths recorded.

A replicated, controlled study in 2009 on bottom fishing grounds in the Baltic Sea off Bornholm, Denmark (10) found that reducing the circumference of a diamond mesh trawl codend improved the size-selectivity of Atlantic cod *Gadus morhua* compared to a larger circumference, and the effect was greatest in combination with mesh orientation turned by 90°. In two of two cases (standard and turned diamond mesh), the estimated length at which cod had a 50% chance of escape was greatest with a smaller circumference codend compared to a larger codend, and was higher in codends that also had meshes turned by 90° (standard, small: 39 cm; standard, large: 34 cm; turned, small: 42 cm, turned, large: 39 cm). Gear trials were done on a research vessel in October 2009 using four codend designs: two with small circumferences (44 and 46 meshes) and two with larger circumferences (91 and 92 meshes), each with or without the netting direction turned by 90° (seven deployments each). Each codend had an average mesh size of 114 mm and was fished one at a time from the same trawl body (see original paper for full gear specifications). A smaller mesh (80 mm) cover attached over each codend collected fish escaping through the meshes. Fish in the codend and cover catches were weighed by species, and cod lengths recorded.

A replicated study in 2008–2010 on fishing grounds in the Western Baltic Sea, off Germany (11) found that bottom trawls with a smaller codend circumference had improved size-selectivity for Atlantic cod *Gadus morhua* and similar size-selectivity for European plaice *Pleuronectes platessa* and European flounder *Platichthys flesus*, compared to larger circumference codends. Irrespective of twine number (single or double) and mesh orientation (standard or turned diamond), the predicted length at which cod had a 50% chance of escape was greater for smaller (44 mesh) circumference codends compared to larger (88 mesh) circumference codends (small: 48 cm, large: 42 cm). There were no differences in the 50% escape lengths between codend mesh circumferences for plaice (small: 25 cm, large: 25 cm) and flounder (small: 24 cm, large: 24 cm), and these were not dependent on netting direction (twine number not tested). Gear trials were done in September 2008 (32 deployments) and March 2010 (18 deployments) by a research vessel in the Arkona Basin. Five diamond mesh codends were tested, constructed using ultra strong polyethylene twine ("Dyneema"): three of 44 meshes circumference and two of 88 meshes circumference, and with either single or double twine, and standard diamond mesh or mesh turned by 90°. A smaller mesh (80 mm) cover attached over each codend collected fish escaping through the meshes. Fish in the codends and covers were weighed by species, and lengths recorded.

A review in 2016 of 40 experimental fishing trials in the northeast Atlantic Ocean (12) found that overall, decreasing the circumference of trawl codends resulted in an increase in the size-selectivity of haddock *Melanogrammus aeglefinus*. The length at which haddock had a 50% chance of escape from the codend was greater by 1.3 cm for every reduction of 10 meshes in circumference around the codend. In addition, the 50% escape length increased by 3.4 cm for every 10 mm increase in codend mesh size and by 1.4 cm for every 1 mm decrease in twine thickness. The study was a meta-analysis of the effects of various changes to codend characteristics, including the number of meshes around the circumference, on the selectivity of haddock in the northeast Atlantic. Data were from 40 trials, covering the years 1991–2009, taken from published studies and other data collected by a Scottish fisheries research organisation (Marine Scotland Science).

A replicated, controlled study in 2014–2015 of three fished areas of seabed in the North Sea, Skagerrak and Baltic Sea, Northern Europe (13) found that choice of modification to bottom trawl gears made by fishers as part of an unrestricted trial, including decreasing codend circumference, increasing mesh size, adding square mesh escape panels and using a coverless trawl, reduced the total discarded catch (fish and invertebrate species) in one of two areas, but not overall, compared to using the regulatory gears. In two of three areas, the average total discarded catch of seven commercial target species (six fish and one invertebrate – see paper for species individual data) was lower for modified trawl gears (Skagerrak: 18 kg/tow, Baltic Sea: 256 kg/tow) compared to the regulated trawls (Skagerrak: 25 kg/tow, Baltic Sea: 328 kg/tow). In the other area (North Sea) average total discard was greater for modified (18 kg/tow) than regulated (13 kg/tow) trawl gears. For all three areas combined, there was no statistical difference in average total discard between modified and regulated trawl gears (modified: 52 kg/tow, regulated: 65 kg/tow). Gear trials were undertaken by twelve Danish bottom trawlers (three to six vessels/area) between December 2015 and July 2015. The fishers were challenged to reduce overall discarding of seven commercial species by modifying or developing new gears and/or changing fishing practice (see original paper for details of all modifications/gears used). Vessels switched between modified and conventional regulatory gears between fishing trips. Data were collected from 421 fishing trips and 2,642 haul deployments.

(1) Reeves S.A., Armstrong D.W., Fryer R.J. & Coull K.A. (1992) The effects of mesh size, cod-end extension length and cod-end diameter on the selectivity of Scottish trawls and seines. *ICES Journal of Marine Science*, 49, 279–288.

(2) Galbraith R.D., Fryer R.J. & Maitland K.M.S. (1994) Demersal pair trawl cod-end selectivity models. *Fisheries Research*, 20, 13–27.

(3) Broadhurst M.K. & Kennelly S.J. (1996) Effects of the circumference of codends and a new design of square-mesh panel in reducing unwanted by-catch in the New South Wales oceanic prawn-trawl fishery, Australia. *Fisheries Research*, 27, 203–214.

(4) Broadhurst M.K., Millar R.B., Kennelly S.J., Macbeth W.G., Young D.J. & Gray C.A. (2004) Selectivity of conventional diamond-and novel square-mesh codends in an Australian estuarine penaeid-trawl fishery. *Fisheries Research*, 67, 183–194.

(5) O'Neill F.G., Graham, N., Kynoch R.J., Ferro R.S.T., Kunzlik P.A. & Fryer, R.J. (2008) The effect of varying cod-end circumference, inserting a 'flexi-grid' or inserting a Bacoma type panel on the selectivity of North Sea haddock and saithe. *Fisheries Research*, 94, 175–183.

(6) Broadhurst M.K. & Millar R.B. (2009) Square-mesh codend circumference and selectivity. *ICES Journal of Marine Science*, 66, 566–572.
(7) Graham K.J., Broadhurst M.K. & Millar R.B. (2009) Effects of codend circumference and twine diameter on selection in south-eastern Australian fish trawls. *Fisheries Research*, 95, 341–349.
(8) Sala A. & Lucchetti A. (2010) The effect of mesh configuration and codend circumference on selectivity in the Mediterranean trawl *Nephrops* fishery. *Fisheries Research*, 103, 63–72.
(9) Sala A. & Lucchetti A. (2011) Effect of mesh size and codend circumference on selectivity in the Mediterranean demersal trawl fisheries. *Fisheries Research*, 110, 252–258.
(10) Wienbeck H., Herrmann B., Moderhak W. & Stepputtis D. (2011) Effect of netting direction and number of meshes around on size selection in the codend for Baltic cod (*Gadus morhua*). *Fisheries Research*, 109, 80–88.
(11) Herrmann B., Wienbeck H., Stepputtis D., Krag L. A., Feekings J. & Moderhak W. (2015) Size selection in codends made of thin-twined Dyneema netting compared to standard codends: A case study with cod, plaice and flounder. *Fisheries Research*, 167, 82–91.
(12) Fryer R.J., O'Neill F.G. & Edridge A. (2016) A meta-analysis of haddock size-selection data. *Fish and Fisheries*, 17, 358–374.
(13) Mortensen L.O., Ulrich C., Eliasen S. & Olesen H.J. (2017) Reducing discards without reducing profit: free gear choice in a Danish result-based management trial. *ICES Journal of Marine Science*, 74, 1469–1479.

2.43 Modify the design or configuration of trawl doors

- **Three studies** examined the effects of modifying the design or configuration of trawl doors on marine fish populations. One study was in the Tasman Sea[1], one in the Clarence Estuary[2] and one in Lake Wooloweyah[3] (all in Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (3 STUDIES)

- **Reduction in unwanted catch (3 studies):** Three replicated, controlled studies (one paired) in the Tasman Sea[1], the Clarence Estuary[2] and Lake Wooloweyah[3] found that modified or different designs of trawl doors caught similar amounts of unwanted fish overall, compared to conventional door types. However, one study found fewer of one of five[3] individual unwanted fish species were caught with modified doors.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Trawl doors are large wooden boards or metal plates (otter boards) attached to the mouth of the trawl net by “bridles” and keep the mouth of the trawl net open as it is pulled through the water. As they are towed through the water, trawl doors and the attached bridle system cause physical damage to the seabed and herd fish into the path of the trawl (Dickson 1993). The design of trawl doors can be modified, for instance by using smaller otter boards, mounting otter boards on a sled, or changing the angle of towing attack, to reduce sediment penetration. Reducing physical contact with the seabed, and therefore sediment penetration, may reduce the herding effect of the doors and bridles and the amount of unwanted fish that move into the path of the trawl gear.

For related interventions describing other modifications to the overall design of different types or parts of trawl gear is summarized under '*Fishing gear modification - Modify the design or configuration of trawl gear (mixed measures)*', *'Change the size of the main body of a trawl net'*, *'Decrease the circumference or diameter of the codend of a trawl net'*, *'Modify a bottom trawl to raise parts of the gear off the seabed during fishing'* and *'Modify design or arrangement of tickler chains/chain mats in a bottom trawl'*.

Dickson W. (1993) Estimation of the capture efficiency of trawl gear. II: Testing a theoretical model. *Fisheries Research*, 16, 255–272.

A replicated, controlled study in 2014 of an area of seabed in the Tasman Sea off New South Wales, Australia (1) found that triple rigged otter trawls with different otter board designs (two types) caught higher amounts of one of six discarded fish species, and similar amounts of discarded catch overall (fish and invertebrates combined), compared to a conventional door type. For unwanted fish, catch rates of only one of six species, spiky flathead *Ratabulus diversidens*, differed between door designs and was lower with the conventional doors than either of the non-conventional designs (restrained: 0.03, batwing: 0.07, conventional: 0.01 kg/ha). Catches of long spine flathead *Platycephalus longispinis*, small-toothed flounder *Pseudorhombus jenynsii*, red bigeye *Priacanthus macracanthus*, long-finned gurnard *Lepidotrigla argus* and eastern bluespotted flathead *Platycephalus caeruleopunctatus* were similar between door designs (data reported as statistical model results). The average catch rates of all unwanted catch (fish and invertebrates combined) was not significantly different between "restrained" flat, rectangular doors (2.6–3.2 kg/ha), "batwing" doors (3.2–3.5 kg/ha) and the conventional flat, rectangular doors (4.1–4.6 kg/ha). In addition, catches of commercial target eastern king prawns *Penaeus plebejus* were similar across trawl designs (see paper for data). Fifteen trawl deployments/door type were made in July 2014 using a triple-rigged trawl fitted with either conventional flat-rectangular otter doors (2.0 × 0.8 m, angle of 42°), "restrained" flat-rectangular doors (same doors as conventional with a line attached to the central sleds to minimise door spread), or "batwing" doors, comprising a plastic "sail" mounted on a main stainless steel sled at an angle of 20°. Trawls were towed for an average of 8.6 km at an average depth of 55 m. Full details of trawl design are provided in the original study.

A replicated, paired, controlled study in 2013 in an area of seabed in the Clarence Estuary, New South Wales, Australia (2) found that using a novel "batwing" design of otter boards on a shrimp trawl did not reduce the unwanted catch of four of four fish species or the overall discarded catch (fish and invertebrates), compared to three different conventional otter board designs. Average catch number of four of four unwanted fish species was similar between the batwing design and the three other conventional designs: forktail catfish *Neoarius graeffei* (batwing: 6.4, flat-rectangular: 7.7, kilofoil: 6.7, cambered: 5.6 fish), southern herring *Herklotsichthys castelnaui* (batwing: 2.7, flat-rectangular: 1.6, kilofoil: 1.1, cambered: 1.9 fish) mulloway *Argyrosomus japonicas* (batwing: 1.9, flat-rectangular: 1.8, kilofoil: 2.1, cambered: 1.7 fish) and yellowfin bream *Acanthopagrus australis* (date reported as model results). Average catch weight of all unwanted catch (fish and invertebrates combined) was similar with the batwing design (0.5 kg) compared to the flat-rectangular (0.4 kg), kilofoil (0.3 kg) and cambered board designs (0.4 kg). The batwing design comprised a sled and sail on a steel boom and mast (61 kg, 1.1 × 1.2 m) set to remain at a constant angle of 20° from the towing direction. The conventional designs were standard flat-rectangular boards (52 kg, 1.4 × 0.6 m), steel kilofoil boards with three vertical foils in a rectangular frame (63 kg, 1.3 × 0.6 m) and cambered boards with a single cambered foil over the boards length (53 kg, 1.1 × 0.7 m). Twenty-four 30-min paired trawl deployments (blocks of two door types towed from each side of the vessel) were performed with each board design on a 10 m trawler in depths of 4–18 m during May 2013 using a 41 mm mesh.

A replicated, controlled study in 2014 in lagoon waters in Lake Wooloweyah, New South Wales, Australia (3) found that using an alternative "batwing" trawl door design reduced the number of one of five unwanted fish species caught, but not the overall amount of unwanted fish caught, compared to a conventional door type. Compared to the conventional door design, the batwing design reduced the number of bridled gobies *Arenigobius bifrenatus* caught/500 m by 25%, but catches of unwanted southern herring *Herklotsichthys castelnaui*, pink-breasted siphonfish *Siphamia roseigaster* and Australian anchovy *Engraulis australis* were similar (data reported as statistical model results). Whitebait *Hyperlophus vittatus* catch increased by 91%. The total unwanted fish catch was similar between batwing and conventional designs (data reported as statistical model results). In addition, catch weight/500 m of the commercial target school prawns *Metapenaeus macleayi* was reduced by 72%. During the Australian autumn in 2014, two pairs of otter boards (batwing and conventional) were deployed one at a time on a 6 m beam trawl from a 10 m trawler in 1-2 m of water. Batwing boards had a main sled at 0° angle of attack and a sail offset by 20° attached to a boom and mast, with an area of 0.74 m^2. The conventional design was flat-rectangular otter boards with an area of 0.77 m^2 and a 35° angle of attack (see original paper for gear specifications). Thirty-six replicate trawls were completed using each pair of boards.

(1) Broadhurst M.K., Sterling D.J. & Millar R.B. (2015) Modifying otter boards to reduce bottom contact: effects on catches and efficiencies of triple-rigged penaeid trawls. *Fisheries Management and Ecology*, 22, 407–418.

(2) McHugh M.J., Broadhurst M.K., Sterling D.J. & Millar R.B. (2015) Comparing three conventional penaeid-trawl otter boards and the new batwing design. *Fisheries Research*, 167, 180–189

(3) McHugh M.J., Broadhurst M.K., Sterling D.J., Millar R.B., Skilleter G. & Kennelly S.J. (2015) Relative benthic disturbances of conventional and novel otter boards. *ICES Journal of Marine Science*, 72, 2450–2456.

2.44 Modify a bottom trawl to raise parts of the gear off the seabed during fishing

- **Two studies** examined the effects of modifying a bottom trawl to raise parts of the gear off the seabed during fishing on marine fish populations. One study was in the Gulf of Carpentaria[1] (Australia) and one was in the Atlantic Ocean[2] (USA).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (2 studies):** Two replicated studies (one randomized and both controlled) in the Gulf of Carpentaria[1] and the Atlantic Ocean[2] found that bottom trawls with parts of the gear raised off the seabed caught fewer unwanted sharks, other elasmobranchs and fish[1] and fewer of three of seven unwanted fish species[2] compared to conventional trawls.

Background

Trawling involves towing a trawl net through the water by one or more fishing vessels. Bottom trawl nets consist of various components, some of which are in physical contact with the seabed during fishing. These gear components can contribute to the catching process by forcing species to swim off the seabed and herding them into the net. The footrope, for example, consists of a rope or wire across the lower edge of the trawl mouth that creates weight to keep the trawl net on or near the seabed. The configuration of the footrope varies between trawls and is different between different seabed habitats and target species. Different footrope designs affect the catch composition (Hannah *et al*. 2003) and the extent to which the gear is in contact with the seabed and hence the amount of physical disturbance (Jones 1992). The trawl bridles are lines that attach the trawl to the otter boards, which keep the trawl net open during towing and also contribute to herding fish into the net. Raising such parts of the gear off the seabed, for example with floats, may therefore reduce seabed bottom contact and the amount of unwanted catch. Behavioural information may also be used to avoid catching certain species. For example, Krag *et al.* (2010) demonstrated how unwanted cod may escape beneath a trawl with its fishing line raised 60 cm above the seabed while targeted haddock are retained.

For related interventions describing other modifications to the overall design of different types or parts of trawl gear is summarized under '*Fishing gear modification - Modify the design or configuration of trawl gear (mixed measures)*', '*Change the size of the main body of a trawl net*', '*Decrease the circumference or diameter of the codend of a trawl net*', '*Modify the design or configuration of trawl doors*' and '*Modify design or arrangement of tickler chains/chain mats in a bottom trawl*'.

Hannah R.W. & Jones S.A. (2003) Measuring the height of the fishing line and its effect on shrimp catch and bycatch in an ocean shrimp (*Pandalus jordani*) trawl. *Fisheries Research,* 60, 427–438.

Jones J.B. (1992) Environmental impact of trawling on the seabed: a review. *New Zealand Journal of Marine and Freshwater Research*, 26, 59–67.

Krag L.A., Holst R., Madsen N., Hansen K. & Frandsen R.P. (2010) Selective haddock (*Melanogrammus aeglefinus*) trawling: Avoiding cod (*Gadus morhua*) bycatch. *Fisheries Research*, 101, 20–26.

A replicated, randomized, controlled study in 1993 in two areas of seabed in the Gulf of Carpentaria, Australia (1) found that unwanted catch of sharks *Carcharinidae*, other sharks/rays *Elasmobranchii* and non-commercial fish species was lower in bottom trawls rigged to fish above the seabed (no groundrope), compared to a conventional trawl with the groundrope in contact with the seabed. Overall, catch rates of unwanted sharks were lower for both raised trawl configurations, 0.4–0.5 m above the seabed (3 kg/h) and 0.8–0.9 m above the seabed (1 kg/h) compared to the conventional trawl (5 kg/h). No other sharks/rays were caught in either modified trawl, but 58 kg/h were caught in the conventional trawl. Catch of unwanted fish species was also lower with the trawl 0.4–0.5 m above the seabed (62 kg/h) and at 0.8–0.9 m above the seabed (12 kg/h) than in the conventional trawl (190 kg/h). In addition, catch rates were similar between both modified trawls and the conventional trawl for all 12 target or commercially valuable species caught (see original paper for data). In November 1993, two 18 × 18 km sites were trawled at 41–58 m depths with three trawl designs with 50 mm mesh codends: two trawls with the groundrope removed, and rigged to fish at either 0.4–0.5 m or 0.8–0.9 m above the seabed by means of floats on the headline floats and weights on the footrope, and one conventional trawl with a 170 kg footrope (see original paper for gear configurations). Sites were trawled alternately for three days at a time (five trawls a day, in separate grids) using a different gear each day, with the gear type randomly re-ordered each time. All catch species were identified and weighed.

A replicated, controlled study in 2011 of an area of seabed in the Gulf of Maine, North Atlantic Ocean off Portland, USA (2) found that the effect of modifying a shrimp trawl to raise the connecting wires between the doors and net (bridles) off the seabed on unwanted fish catch varied between species, compared to conventional trawls with bridles in contact with the seabed. Of seven unwanted (non-commercial target) fish species/groups monitored, average catch rates were lower in modified trawls for three: long rough dab *Hippoglossoides platessoides* (3 kg/h), redfish *Sebastes fasciatus* (2 kg/h) and all flounders combined Pleuronectoidei (4 kg/h), compared to conventional trawls (plaice: 2, redfish: 1, flounders: 3 kg/hr). Catch rates of silver hake *Merluccius bilinearis,* Atlantic herring *Clupea harengus*, red hake *Urophycis chuss* and witch flounder *Glyptocephalus cynoglossus* were similar between gears (raised bridles: 2–38 kg/h, conventional: 1–35 kg/h). In addition, catch rates of the commercial target Northern shrimp *Pandalus borealis* was similar between gears (raised bridles: 141 kg/h, conventional: 146 kg/h). Data were collected on a commercial vessel from 30 trawl deployments/gear type between March–May 2011. For the modified gear (raised bridles), the wire bridles were replaced with polypropylene rope, while the conventional gear had steel wires. Codend mesh size was 43 mm. Tows were between 90–155 m, 2.3 knots and 1 h duration. All catch was identified and counted.

(1) Brewer D., Eayrs S., Mounsey R. & Wang Y.G. (1996) Assessment of an environmentally friendly, semi-pelagic fish trawl. *Fisheries Research,* 26, 225–237.
(2) He P., Rillahan C. & Balzano V. (2015) Reduced herding of flounders by floating bridles: application in Gulf of Maine Northern shrimp trawls to reduce bycatch. *ICES Journal of Marine Science*, 72, 1514–1524.

2.45 Modify design or arrangement of tickler chains/chain mats in a bottom trawl

- **Two studies** examined the effects of modifying the design or arrangement of tickler chains in a bottom trawl on marine fish populations. One was in the North Sea[1] (Netherlands/UK) and one was in the Atlantic Ocean[2] (Scotland).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (2 studies):** One of two replicated, paired, controlled studies in the North Sea[1] and Atlantic Ocean[2] found that removing the tickler chain from a trawl reduced catches of non-commercial target skates/rays and sharks, and individuals were larger, compared to trawling with the chain[2]. The study also found that catches of commercial target species were typically unaffected. The other study[1] found that two modified tickler chain arrangements did not reduce discarded fish catch compared to a standard arrangement.

Background

Trawl nets are towed through the water by fishing vessels. Some types of bottom trawl, particularly beam trawls, are rigged with 'tickler' chains or a chain mat, that spread from one side of the trawl mouth to the other, contacting the seabed. Tickler chains and chain mats physically disturb the seabed to increase the likelihood of animals entering the mouth of the trawl. However, they often cause unwanted species to enter the trawl as well as those targeted commercially. Modifying tickler chain arrangement (such as reducing the size of chain links, or attaching only one end of the chain to the beam; Bergman & Van Santbrink 2000; Broadhurst *et al*. 2015), or even removing them altogether, may reduce the seabed disturbance and therefore result in fewer unwanted fish species/sizes being retained by the gear.

For related interventions describing other modifications to the overall design of different types or parts of trawl gear is summarized under '*Fishing gear modification - Modify the design or configuration of trawl gear (mixed measures)*', '*Change the size of the main body of a trawl net*', '*Decrease the circumference or diameter of the codend of a trawl net*', '*Modify the design or configuration of trawl doors*' and '*Modify a bottom trawl to raise parts of the gear off the seabed during fishing*'.

Bergman M.J.N. & Van Santbrink J.W. (2000) Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. *ICES Journal of Marine Science*, 57, 1321–1331.

Broadhurst M.K., Sterling D.J. & Millar R.B. (2015) Traditional vs. novel ground gears: Maximising the environmental performance of penaeid trawls. *Fisheries Research*, 167, 199–206.

A replicated, paired, controlled study in 1999 on bottom fishing grounds in the North Sea between the Netherlands and UK (1) found that two different modifications to the way tickler chains were attached to a beam trawl (hanging parallel from, or in loops along, the beam) did not reduce the discarded fish catch, compared to a conventional tickler chain arrangement. For unwanted fish (undersized commercial target species and all other non-target species), there were no differences in catches between the modified and conventional tickler chain arrangements, except for small whiting *Merlangius merlangus*, of which fewer were caught by the modified gear (data not reported). Data were collected from a series of beam trawl deployments along six parallel strips on the seabed (2,000 m × 30 m) using two modified and one conventional tickler chain arrangement. In March-April 1999, a total of 72 deployments were carried out with three different configurations of parallel chains (numbers and spacing, connected pairs) hung along the beam. In October 1999, a total of 35 deployments were undertaken with three configurations of chains hung in loops from the beam. In addition, a standard trawl with conventional tickler chain arrangement (attached to the shoe plates on either end of the beam) was towed simultaneously during each deployment. All catch was weighed.

A replicated, paired, controlled study in 2005 in an area of seabed in deep water in the Atlantic Ocean off the Isle of Skye, Scotland, UK (2) found that removal of the tickler chain from a bottom trawl reduced the capture of unwanted skates/rays (Batoidea) and unwanted sharks (Chondrichthyes) compared to a standard trawl with a tickler chain. Overall, trawl gear without a tickler chain decreased the catch of skates/rays (four species) and sharks (three species) compared to a trawl with a tickler chain (skates/rays, without: 198 individuals, with: 625 individuals; sharks, without: 993 individuals, with:

1,357 individuals). For the more commercially valuable species, overall catch rates of three flatfish species (Pleuronectidae) and two cod-like species (Gadidae) were similar between trawls, however, catch rates of two anglerfish *Lophius* sp. decreased with a tickler chain (see paper for data). Trials took place onboard a commercial fishing vessel in October 2005. A total of 17 paired deployments of standard bottom fish trawls, one with the tickler chain removed, were made, parallel to one another, at 120–170 m depth.

(1) van Marlen B., Bergman M.J.N., Groenewold S. & Fonds M. (2005) New approaches to the reduction of non-target mortality in beam trawling. *Fisheries Research*, 72, 333–345.

(2) Kynoch R.J., Fryer R.J. & Neat F.C. (2015) A simple technical measure to reduce bycatch and discard of skates and sharks in mixed-species bottom-trawl fisheries. *ICES Journal of Marine Science*, 72, 1861–1868.

2.46 Use a different twine type in a trawl net

- **Five studies** examined the effects of using a different twine type in a trawl net on marine fish populations. Two studies were in each of the North Sea[1,5] (UK) and the Western Baltic Sea[3,4] (Denmark/Germany), and one study was in the Adriatic Sea[2] (Italy).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (5 STUDIES)

- **Improved size-selectivity of fishing gear (5 studies):** Four of five replicated studies (four controlled) in the North Sea[1,5], Baltic Sea[3,4] and Adriatic Sea[2] found that using a different twine type (twine thickness and construction material) improved the size-selectivity of bottom fish[2], haddock[1], Atlantic cod[3,4], plaice[3,4] and flounder[4], compared to thinner or other twine materials. One study[5] found that selectivity of non-target haddock and plaice was similar for three different twine diameters. One of these studies[3] also found that size-selectivity of fish was influenced by twine number and mesh orientation, while another[4] found no effect of twine number and mesh orientation, but cod selectivity increased with a smaller codend circumference.

Background

Although many commercial fishers must abide to set rules around the size of mesh they can use in their trawls, altering the thickness of mesh twine can impact the effectiveness of the mesh size. A thin twine allows the mesh to be more flexible which might help more fish smaller than the mesh opening to escape when forcing themselves against the trawl (Lowry & Robertson 1996) but the thinner twine might be weaker against heavy catch loads. A thick twine creates a more rigid, strong mesh (Lowry & Robertson 1996). It is believed that this thicker twine could present a greater visual barrier to fish which might discourage them from escape attempts.

Evidence for similar interventions is summarized under '*Fishing gear modification - Modify the design or configuration of trawl gear (mixed measures)*'. See also, '*Use a larger mesh size*'.

Lowry N. & Robertson J.H.B. (1996) The effect of twine thickness on cod-end selectivity of trawls for haddock in the North Sea. *Fisheries Research*, 26, 353–363.

A replicated, controlled study in 1993 in a seabed area in the North Sea, UK (1) found that using a thinner twine thickness in a fish trawl codend improved the size-selectivity of haddock *Melanogrammus aeglefinus* compared to thicker twine. The length at which haddock had a 50% chance of escaping was lower with thinner twine thickness (thin: 25 cm, thick: 24 cm). The authors noted the difference would be expected to be larger if the two codends had been of the same mesh size. Data were collected in the Moray Firth off Fraserburgh in June 1993 from 13 experimental trawl deployments by a commercial trawler in depths of 91–100 m (2 h duration, 2.5 kn speed). Separate deployments of two codends with different twine thicknesses were tested, 3.5 mm (7 hauls) and 5.2 mm (6 hauls). Measured mesh size was 95 mm for the thin twine and 100 mm for the thick twine. A small mesh cover attached over each codend collected fish escaping through the meshes. Codend and cover catches were recorded, and haddock lengths measured.

A replicated, controlled study in 2004 of one shallow inshore and one deeper offshore seabed area, in the central Adriatic Sea, off Italy (2) found that using a thinner diameter of twine in the codend of a trawl net improved the size-selectivity of five of five fish species. Across both areas, the length at which fish had a 50% chance of escaping was highest using thin twine compared to thick twine for whiting *Merlangius merlangus* (thin: 11 cm, thick: 8 cm), European hake *Merluccius merluccius* (thin: 9 cm, thick: 8 cm), red mullet *Mullus barbatus* (thin: 9 cm, thick: 7 cm), common pandora *Pagellus erythrinus* (thin: 9 cm, thick: 7 cm) and poor cod *Trisopterus minutus capelanus* (thin: 10 cm, thick: 7 cm). Data were collected by research vessel from trawl deployments on two different fishing grounds. In the offshore area (35 nm from the coast, 70 m depth), 34 trawl deployments were done between April 2004–May 2004. In the inshore area (5 nm off the coast near Ancona, 20 m depth), 20 deployments were made in September 2004. Two codends of different twine thicknesses were tested: 2.4 mm diameter (thin) and 2.9 mm diameter (thick – industry standard) and alternated daily on the same trawl net body. Small mesh covers attached over each codend sampled the fish escaping through the meshes.

A replicated study in 2011 of a fished area of seabed in the western Baltic Sea, off Denmark/Germany (3) found that size-selectivity of Atlantic cod *Gadus morhua* and plaice *Pleuronectes platessa* increased with decreasing twine thickness of a trawl net codend, and was also influenced by twine number (single or double) and mesh orientation (0° or turned by 90°). The estimated length at which cod had a 50% chance of escaping increased with decreasing thickness of single twine mesh (thinnest: 42 cm, thickest: 31–39 cm), irrespective of mesh orientation (however the difference between mesh orientations was greater at thicker twine thicknesses – see paper for data). The same increase in size-selectivity with decreasing twine thickness was found for plaice (thinnest: 24–25 cm, thickest: 24–25 cm). In addition, for a given twine thickness, turning mesh orientation by 90° increased selectivity of cod but decreased selectivity of plaice; and changing from single to double twine reduced selectivity of cod (see paper for data). Data were collected in March–April 2011 from 43 alternate deployments of 12 codends with different combinations of twine thickness (3 mm to 8 mm), twine number (single or double) and mesh orientation (standard diamond or turned by 90°). Haul duration was 90–180 minutes, at depths of 32–49 m. A small mesh cover attached over each codend collected fish escaping through the meshes. Cod and plaice in the codends and covers were sampled, and their lengths measured.

A replicated, controlled study in 2008 in an area of seabed in the western Baltic Sea off Denmark/Germany (4) found that trawl codends made of a flexible thin-twined netting improved the size-selectivity of cod *Gadus morhua,* plaice *Pleuronectes platessa* and flounder *Platichthys flesus,* compared to a conventional polyethylene twine, and for the flexible netting, there were no effects of changes to the number of twines (single or double) and netting orientation (0° or 90°), but cod selectivity decreased with increased codend circumference. For all three species, the length at which fish had a 50% chance of escaping was greater in codends made of 2.5 mm flexible thin twine compared to standard 5 mm single twine polyethylene codends (data reported graphically). For different designs of the flexible thin twine, there was no effect of twine number (cod tested only) or mesh orientation, but reducing the number of meshes in the codend circumference increased the size selection of cod but did not affect the size selection of plaice and flounder (data presented graphically – see paper). Data were collected on two surveys in September 2008 and March 2010. A total of 70 trawl deployments were carried out using different codend types, alternately fitted to the same trawl net. Five codends were constructed from a thin but ultrastrong twine ("Dyneema") and differed in number of twines, netting orientation, and mesh circumference. Two were standard polyethylene codends (thicker and less flexible twine). Small mesh covers attached over each codend collected fish escaping through the meshes.

A replicated, controlled study in 2003 of bottom fishing grounds in the North Sea, UK (5) found that changing the thickness of twine (three diameters) in a trawl net codend did not improve the size-selectivity of unwanted haddock *Melanogrammus aeglefinus* or plaice *Pleuronectes platessa.* The lengths at which fish had a 50% chance of escaping capture were similar for all three twine thicknesses for both haddock (thin: 35–36 cm, medium: 35–36 cm, thick: 31–35 cm) and plaice (thin: 28.6–29.4 cm, medium: 28.6–30 cm, thick: 28.4–29.8 cm). Data were collected from 30 trawl deployments on a commercial fishing vessel east of Scotland in October 2003. Three twine sizes were tested (thin: 4.1 mm, medium: 4.6 mm, thick/conventional: 5.1 mm) during separate hauls and using the covered codend method to collect fish escaping through the meshes. Haul duration was 40–211 min. Haddock and plaice lengths were measured and if catches were large, subsampled.

(1) Lowry N. & Robertson J.H.B. (1996) The effect of twine thickness on cod-end selectivity of trawls for haddock in the North Sea. *Fisheries Research*, 26, 353–363.

(2) Sala A., Lucchetti A. & Buglioni G. (2007) The influence of twine thickness on the size selectivity of polyamide codends in a Mediterranean bottom trawl. *Fisheries Research*, 83, 192–203.

(3) Herrmann B., Wienbeck H., Moderhak W., Stepputtis D. & Krag L.A. (2013) The influence of twine thickness, twine number and netting orientation on codend selectivity. *Fisheries Research,* 145, 22–36.

(4) Herrmann B., Wienbeck H., Stepputtis D., Krag L.A., Feekings J & Moderhak W. (2015) Size selection in codends made of thin-twined Dyneema netting compared to standard codends: A case study with cod, plaice and flounder. *Fisheries Research*, 167, 82–91.

(5) O'Neill F.G., Kynoch R.J., Blackadder L., Fryer R.J., Eryasar A.R., Notti E. & Sala A. (2016) The influence of twine tenacity, thickness and bending stiffness on codend selectivity. *Fisheries Research*, 176, 94–99.

2.47 Use a separator trawl

- **Two studies** examined the effect of using a separator trawl on marine fish populations. One study was in the North Sea[1] (UK) and the other in the Atlantic Ocean[2] (Portugal).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (2 studies):** One replicated, randomized study in the North Sea[1] found that a separator trawl separated unwanted cod from target fish species into the lower codend, where a larger mesh size allowed more unwanted smaller cod to escape capture. One replicated study in the Atlantic Ocean[2] found that a separator trawl fitted with a square-mesh escape panel caught less of one of two unwanted fish species in a crustacean fishery.

Background

Capture of fish in trawls depends on the behavioural reaction of fish to the presence of the net. When a trawl approaches, fish turn and swim in the same direction as the net until exhausted, at which point they enter the net, albeit at different vertical positions. Some species (e.g. haddock *Melanogrammus aeglefinus*, whiting *Merlangius merlangus*) swim high in the net and others (e.g. cod *Gadus morhua*, flatfish) stay low in the trawl. In separator trawls, a horizontal net panel is fitted into the trawl net that splits the trawl into upper and lower sections and into separate upper and lower codends. Catch is then separated into each codend, which can be made of different mesh sizes to allow more or less of the catch in each to be retained. For example, in mixed flatfish and haddock fisheries, separator trawls with larger mesh upper codends may allow less unwanted cod to be caught whilst retaining target catches (Ferro *et al.* 2007).

Evidence for similar interventions describing the effects of using modified trawl types to reduce unwanted catch is summarized under '*Fishing gear modification - Use a topless (coverless) trawl*' and '*Use an electric (pulse) trawl*'.

Ferro R.S.T., Jones E.G., Kynoch R.J., Fryer R.J. & Buckett, B. E. (2007). Separating species using a horizontal panel in the Scottish North Sea whitefish trawl fishery. *ICES Journal of Marine Science*, 64, 1543–1550.

A replicated, randomized study in 1994 in two areas of seabed in the North Sea, UK (1) found that using a separator trawl separated the majority of unwanted Atlantic cod *Gadus morhua* into a lower trawl net from other target fish species that were retained in an upper trawl net, and size-selectivity in the lower trawl net increased with increasing mesh size. Across five trawl deployments, the probability of cod entering the lower codend was 0.87 (min: 0.74, max: 0.96). The length at which cod had a 50% chance of escape was 33.8 cm in the lower codend with a 100 mm mesh size (min: 26.2, max: 53.1 cm) and 57.6 cm in the lower codend with a 140 mm mesh size (min: 42.5, max: 80.1 cm). Results were not tested for statistical significance. Five experimental trawl deployments were undertaken with a separator trawl off Whitby, northeast England in March 1994 and in the Moray Firth, Scotland in November 1994. The trawl was a standard trawl divided horizontally by a panel behind the footrope into two codends. The upper codend had 100 mm mesh size and two randomly assigned lower codends had 100 mm or 140 mm mesh size. Full details of trawl design are provided in the original study.

A replicated study in 1993–1994 of an area of seabed in the Atlantic Ocean off the coast of Portugal (2) found that shrimp trawl nets combining a separator panel with a square mesh escape window reduced the catch of one of two unwanted fish species, compared to a square mesh window alone. Overall, the percentage escape of boarfish *Capros aper* was higher by 10–44% (105–1,430 kg) from nets with a separator panel compared to 17% (896 kg) with no panel and amounts of escaped blue whiting

Micromesistius poutassou were similar (67–81%; panel: 58–187 kg, no panel: 107 kg). In addition, the escape rates of boarfish increased with increasing mesh size of the square mesh panel (70 mm: 10%, 100 mm: 44%). Escaped catch of the target species rose shrimp *Parapenaeus longirostris* and Norway lobster *Nephrops norvegicus* was <1–28% in nets with panels compared to 1–24% with no panel. Four fishing trials were undertaken, each testing one of four trawl nets: three with different separator panel/escape window mesh size combinations and one with the window alone (see paper for specifications). For each net, six or seven experimental hauls were conducted in July 1993 to May 1994 off the Algarve coast. Fish and crustaceans that escaped through the square mesh window were collected in a small mesh cover mounted over the escape window. Codend (top and bottom) and cover catches were sorted by species, weighed and lengths recorded.

(1) Cotter A.J. R., Boon T.W. & Brown C.G. (1997) Statistical aspects of trials of a separator trawl using a twin rig trawler. *Fisheries Research*, 29, 25–32.
(2) Campos A. & Fonseca P. (2004) The use of separator panels and square mesh windows for by-catch reduction in the crustacean trawl fishery off the Algarve (South Portugal). *Fisheries Research*, 69, 147–156.

2.48 Use a topless (coverless) trawl

- **Four studies** examined the effect of using a topless or coverless trawl on marine fish populations. Two studies were in the North Sea[1,2] (UK, Norway, Sweden), one study was in the Gulf of Maine[3] (USA) and one study was in the North Sea, Skagerrak and the Baltic Sea[4] (Northern Europe).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (4 STUDIES)

- **Reduction of unwanted catch (4 studies):** Two of four replicated, controlled studies (three paired) in the North Sea[1, 2], Gulf of Maine[3], and North Sea, Skagerrak and Baltic Sea[4] found that using a topless trawl, in one case in combination with another non-conventional trawl type[4], reduced the catch of unwanted Atlantic cod[3] and discards of commercial fish species[4] compared to conventional trawl types. One study[2] found that topless trawls reduced unwanted catches of larger but not smaller haddock and larger Atlantic cod only in one of two cases, compared to standard trawl types. The other[1] found that discarded catches of one of four commercial fish species were reduced in topless trawls.

Background

Trawls may capture significant numbers of unwanted species when they are towed through the water. When a trawl approaches, fish turn and swim in the same direction as the net until exhausted, at which point they enter the net, albeit at different vertical positions. Some species (e.g. haddock *Melanogrammus aeglefinus*, whiting *Merlangius merlangus*) swim high in the net and others (e.g. cod *Gadus morhua*, flatfish) stay low in the trawl (Thomsen 1993). 'Topless', 'coverless' or 'cutaway' trawls are trawl nets with a reduced top panel, or longer headlines than footropes, and exploit these behavioural differences to allow escape of unwanted species by swimming upwards away from the footrope and out of the trawl.

Evidence for similar interventions describing the effects of using modified trawl types to reduce unwanted catch is summarized under '*Fishing gear modification – Use a separator trawl'* and *'Use an electric (pulse) trawl'*.

Thomsen B. (1993) Selective flatfish trawling. *ICES Marine Science Symposium*, 196, 161–164.

A replicated, paired, controlled study in 2005 in an area of seabed in the Farne Deeps in the North Sea off northeast England, UK (1) found that using a topless prawn bottom trawl net (a 'cutaway' trawl) reduced the discarded catches of one of four commercial fish species, compared to a conventional commercial trawl net. Total catches of undersized whiting *Merlangius merlangus* (<27 cm) were lower with the topless/cutaway trawl (whiting: 10,169 fish; compared to the conventional trawl (cutaway: 10,169 fish, conventional: 4,006 fish). Total catches of undersized Atlantic cod *Gadus morhua* (<35 cm) and lemon sole *Microstomus kitt* (<25 cm) were similar between trawl types (cod, cutaway: 110 fish, conventional: 58 fish; lemon sole, cutaway: 1,024 fish, conventional: 895 fish). More undersized plaice *Pleuronectes platessa* (<25 cm) were caught with the cutaway trawl (358 fish) than the conventional trawl (187 fish) however the authors noted that this may have been due to the cutaway trawl maintaining more consistent contact with the seabed. Commercial target Norway lobster *Nephrops norvegicus* catch weights were similar in the cutaway (1,613 kg) and conventional trawls (1,536 kg). Data were collected from 26 experimental trawl net deployments on a commercial vessel in March/April 2005 using twin trawls towed parallel. One of the trawls had a new design of trawl ('cutaway') with a shortened headline, and the other side was a conventional trawl used in the commercial fishery for *Nephrops*. All trawls also included a mandatory square mesh panel in the upper panel. Full details of trawl designs are provided in the original study.

A replicated, paired, controlled study (year not stated) of multiple fished areas of seabed in the North Sea off Norway and Sweden (2) found that use of topless bottom trawls (two designs) reduced the catches of unwanted larger haddock *Melanogrammus aeglefinus* and of unwanted larger cod *Gadus morhua* in one of two cases, compared to standard trawls. Total catch numbers of haddock were lower in both large and small topless trawl designs compared to standard trawls (topless: 20–352 fish, standard: 662–2,467 fish). Catches of cod were lower in a larger, high headline topless trawl (topless: 583, standard: 1,755/trawl) but similar in the smaller trawl with low headline (topless: 941, standard: 1,305/trawl) compared to standard trawls. For both species, the effect was significant only for larger individuals (haddock >19–23 cm and cod >34 cm length). Numbers of commercial target Norway lobster *Nephrops norvegicus* were similar between trawl types (topless: 1,666–1,681 individuals, standard: 1,702–2,057 individuals). Data were collected from 51 comparative trawl deployments in two trials on different commercial vessels (one large, one small), both fishing a topless trawl towed parallel to a similar-size standard trawl. One trial tested a small topless trawl with the upper wings removed and the head rope cut 6.4 m back, and the other a larger topless trawl with the head rope cut 11.3 m back (see paper for full specifications). Catches in each codend were sorted by species and fish lengths measured. Hauls with fewer than 10 individuals of a species were not included for analysis. Study year was not reported.

A replicated, paired, controlled study in 2011 in bottom fishing grounds in the Gulf of Maine off Boston, USA (3) found that using a topless trawl reduced the unwanted catches of cod *Gadus morhua* in a mixed species bottom fishery, compared to a standard trawl. The catch rates of cod were lower with the topless trawl compared to the standard trawl (topless: 182 kg/hr, standard: 374 kg/h). In addition, catch rates were similar between trawl types for four of five species/species groups of commercial value: yellowtail flounder *Limanda ferruginea* (topless: 83 kg/h, standard: 82 kg/h), skates *Rajidae* spp. (topless: 36 kg/h, standard: 32 kg/h), witch flounder *Glyptocephalus cynoglossus* (topless: 22 kg/h, standard: 25 kg/h) and spiny dogfish *Squalus acanthias* (topless: 22 kg/h, standard: 27 kg/h). Catches of long rough dab *Hippoglossoides platessoides* were lower in the topless trawl (topless: 36 kg/h, standard: 49 kg/h), however, the reduction was almost all undersized individuals (data reported as statistical result). Data were collected in May and June 2011 from 30 paired deployments on a commercial fishing vessel using the topless and standard trawl net designs towed in parallel (45 min, 2.6 kt). The headline length of the topless and standard trawls were 46 m and 21 m, respectively, and headline to footrope ratios were 1.7:1 and 0.8:1, respectively. See original paper for full gear specifications.

A replicated, controlled study in 2014–2015 in fishing grounds in the North Sea, Skagerrak and Baltic Sea, Northern Europe (4) found that switching to using a coverless trawl, and various other different trawl gear types/designs, reduced the total discarded catch of seven commercial target species (six fish and one crustacean) compared to conventional trawl types, and the overall effect of using different gear types varied between regions. For one of 12 individual vessels that opted to use a topless trawl (as one of two different gear types used), average total discarded catch of the seven species was lower in the modified trawls (both types combined) compared to the conventional trawl type (modified: 6 kg, conventional: 16 kg). Across all vessels, in two of three regions the average total discarded catch of the seven species was lower in modified trawl types (Skagerrak: 18 kg, Baltic Sea: 256 kg) compared to conventional trawl gears (Skagerrak: 25 kg, Baltic Sea: 328 kg). In the other region (North Sea) discarded catch was higher (modified: 18 kg, conventional: 13 kg). Data were collected from a trial run from December 2014 to July 2015 involving 12 Danish bottom trawlers who were given free choice of trawl gear, in place of the regulatory gear being used, with the challenge of reducing discards. One of the 12 vessels used a 120 mm topless trawl with 1.4–1.6 m vertical opening, as well as a trawl net with a square mesh escape panel (see original paper for other gears types used/vessel). Each vessel switched between using modified and conventional gears between fishing trips.

(1) Revill A., Dunlin G., & Holst R. (2006) Selective properties of the cutaway trawl and several other commercial trawls used in the Farne Deeps North Sea Nephrops fishery. *Fisheries Research*, 81, 268–275.

(2) Krag L.A., Herrmann B., Karlsen J.D. & Mieske B. (2015) Species selectivity in different sized topless trawl designs: Does size matter? *Fisheries Research*, 172, 243–249.

(3) Eayrs, S., Pol, M., Caporossi, S.T. & Bouchard, C. (2017) Avoidance of Atlantic cod (*Gadus morhua*) with a topless trawl in the New England groundfish fishery. *Fisheries Research*, 185, 145–152.

(4) Mortensen L.O., Ulrich C., Eliasen S. & Olesen H.J. (2017) Reducing discards without reducing profit: free gear choice in a Danish result-based management trial. *ICES Journal of Marine Science*, 74, 1469–1479.

2.49 Use an electric (pulse) trawl

- **Three studies** examined the effects of using an electric (pulse) trawl on marine fish populations. The studies were in the North Sea[1,2,3] (Belgium, Netherlands and multiple countries).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR RESPONSE (0 STUDIES)

OTHER (3 STUDIES)

- **Reduction of unwanted catch (3 studies):** Two replicated, paired, controlled studies and one review in the North Sea[1,2,3] found that using an electric/pulse trawl reduced the catches of non-target or undersized (discarded) commercial fish in some or all cases, compared to using a standard trawl.

Background

Pulse-equipped trawls are mainly beam trawls targeting flatfish (sole/plaice), but also shrimps. The tickler chains are replaced by electrodes that give off short electrical pulses, stunning the fish and raising them off the bottom and making them easier to catch (Polet *et al.* 2005). It is a highly controversial method and is prohibited in the USA, China and several other countries. It is also technically illegal in EU waters. However, an exception to the rules allows countries to catch up to 5% of their annual fishing quota in the North Sea using "innovative methods" for research, and the use of pulse trawls predominantly occurs here. The Netherlands is the biggest user of this method and in 2018, there were around 80 trawlers holding permits issued by the Dutch government. Despite attempts to ban it altogether, pulse fishing is still 'allowed' in EU waters until mid-2021. Many fishers and opposers to the method believe it harms the fish it is designed to catch and kills other marine life (Polet *et al.* 2005). However, there is evidence that suggests pulse-equipped trawls catch less unwanted marine life, including unwanted fish, than other trawlers (ICES 2020, Polet *et al.* 2005) and cause less damage to the sea floor (ICES 2020). Furthermore, the body of research assessing the effects of pulse trawling has recently been extended (see references in ICES 2020) and is therefore not within the scope of the current synopsis.

Evidence for similar interventions describing the effects of using modified trawl types to reduce unwanted catch is summarized under '*Fishing gear modification – Use a separator trawl*' and '*Use a topless (coverless) trawl*'.

ICES. (2020) ICES Working Group on Electrical Trawling (WGELECTRA). ICES Scientific Reports, 37, 108 pp.

Polet H., Delanghe F. & Verschoore R. (2005) On electrical fishing for brown shrimp (*Crangon crangon*): II. Sea trials. *Fisheries Research*, 72, 13–27.

A replicated, paired, controlled study in 2000 of an area of seabed in the North Sea, off Belgium (1) found that electric pulse trawls targeting brown shrimp *Crangon crangon* reduced the amount of some unwanted and undersized fish caught compared to standard trawls. Of 12 comparisons, catches of undersized commercial fish were lower in pulse trawls than in standard trawls for whiting *Merlangius merlangus* in four (58–69% lower), sole *Solea solea* in two (41–60%), plaice *Pleuronectes platessa* in five (40–80%) and dab *Limanda limanda* in two comparisons (61–65%). Lower catches in pulse trawls were also reported in non-commercial tub gurnard *Trigla lucerna* (one of three comparisons), pogge *Agonus cataphractus* (three of 12 comparisons), dragonet *Callionymus* spp. (two of 10 comparisons) and goby *Pomatoschistus* spp. (six of 12 comparisons). Catches of six other non-commercial species were similar in both trawl designs. Catches of legal-sized commercial fish were typically similar in pulse trawls and standard trawls, except for lower catches of flounder *Platichthys flesus* (29–37%) and dab (17%) in one and two of 12 comparisons respectively. In addition, undersized shrimp catches were reduced in 11 of 15 cases. In 2000, experimental fishing was undertaken on the Flemish Banks off the Belgian coast using two beam trawls simultaneously, a standard trawl and an experimental electric pulse trawl, with pulse generators fitted to the beam of the trawl in one of two array configurations. Fifty-seven hauls were completed with the experimental trawl being towed on one side of the vessel and the standard trawl on the other. Full details of trawl design and generator configurations are provided in the original study.

A replicated, paired, controlled study in 2011 in an area of seabed in the North Sea, Netherlands (2) found that fishing for flatfish using an electric pulse trawl reduced the catches of discarded fish and undersized plaice *Pleuronectes platessa* and sole *Solea solea* compared to a conventional beam trawl. Average catch rate of all discarded fish (mainly bottom dwelling species – see paper for data for individual species/groups) was reduced by 57% in the pulse trawl (108 fish/ha) compared to the beam trawl (62 fish/ha). Fewer individuals of smaller sizes of the target species plaice and sole were caught in the pulse trawl than the beam trawl (data reported graphically). Data were collected in May 2011 from 126 trawl by three vessels fishing near each other. Two vessels used different types of pulse equipment (data pooled) and the other was a conventional tickler chain beam trawl (see original paper for specifications). Discarded catch was sampled from 33 hauls from each vessel.

A review in 2015 of electrotrawling activity in the North Sea (3) found that electric pulse trawls reduced unwanted catch, but some damage occurred to fish compared to standard trawls. Unwanted catch was lower in pulse trawls in three cases (30–50% less) and catches of commercial sole were lower in one case (13–22%), compared to using tickler chains. In two cases where electric pulses were used, one in Belgium and one in the United Kingdom, catches of small unwanted sole *Solea solea* and other small flatfish were lower compared to standard trawls. In addition, cod *Gadus morhua*, but not lesser-spotted dogfish *Scyliorhinus canicula*, suffered spinal fractures, other injuries and death at all sizes in one case and only at adult sizes in one case, when fish were close to electric fields (injuries 9–70%, death up to 30%). The review summarized the development of electrofishing using trawls in European waters. Controlled studies (field and laboratory) of the effects of electrofishing on fish were also reviewed.

(1) Polet H., Delanghe F. & Verschoore R. (2005) On electrical fishing for brown shrimp (*Crangon crangon*): II. Sea trials. *Fisheries Research*, 72, 13–27.

(2) van Marlen B., Wiegerinch J.A.M., Os-Koomen E.v. & Barneveld E.v. (2014) Catch comparison of flatfish pulse trawls and a tickler chain. *Fisheries Research,* 151, 57–69.

(3) Soetaert M., Decostere A., Polet H., Verschueren B. & Chiers K. (2015) Electrotrawling: a promising alternative fishing technique warranting further exploration. *Fish and Fisheries*, 16, 104–124.

2.50 Use a square mesh instead of a diamond mesh codend in a trawl net

- **Twenty-six studies** examined the effects of using a square mesh instead of a diamond mesh codend in a trawl net on marine fish populations. Five studies were in the North Atlantic Ocean[3,8,9,10,16] (Canada, Portugal, USA), four were in the Aegean Sea[4,5,7,20] (Greece, Turkey), three were in the Mediterranean Sea[12,14,15] (Spain) and the Tasman Sea[11,19,25] (Australia), two studies were in each of the English Channel[1,18] (UK), the Adriatic Sea[17,23] (Italy) and the South Pacific Ocean[13,24] (Australia, Chile), and one study was in each of the Greenland Sea[2] (Iceland), the North Pacific Ocean[6] (USA), the Bristol Channel[21] (UK), the Kattegat and the Skagerrak[22] (Denmark) and the Coral Sea[26] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** One of two replicated, paired, controlled studies in the Aegean Sea[20] and Bristol Channel[21] found that the short-term survival of two of six fish species[20] was higher after escaping through a square mesh compared to a diamond mesh codend. The other study[21] reported that skate caught in a square mesh codend had a higher overall survival likelihood than those caught in a diamond mesh codend.

BEHAVIOUR (0 STUDIES)

OTHER (25 STUDIES)

- **Reduction of unwanted catch (16 studies):** Ten of 16 replicated, controlled studies (including five paired, three randomized and three randomized and paired) in the Greenland Sea[2], Aegean Sea[4,5,7], Atlantic Ocean[10], Tasman Sea[11,19,25], Pacific Ocean[6,13,24], Mediterranean Sea[14,15], English Channel[18], Bristol Channel[21] and Coral Sea[26], found that square mesh codends reduced the unwanted (non-target or non-marketable/discarded) catches of all fish species monitored[2,13,14,18,21,25], young individuals of half[11] or most[10] commercially targeted fish, total unwanted catch (fish and invertebrates)[26], and discarded fish in deeper but not shallower fishing areas[15], compared to diamond mesh codends; and two of those studies[25,26] also found that there was a variable effect on unwanted catch between individual fish species/groups. Four studies[4,5,6,19] found no reduction in catches of unwanted small rockfish and flatfish[6], three of four commercially important bottom fish species[4], total unwanted catch (fish and invertebrates)[5,19], or the total number of unwanted species (fish and invertebrates)[5], compared to diamond mesh codends. One study[7] found that square mesh codends retained more fish overall than diamond mesh but varied for individual species by fish shape and size. One study[24] found that unwanted fish catch depended on codend mesh size as well as configuration (square or diamond). Two of the studies[6,7], where square mesh codends had no or a varied effect, also found that size selectivity increased with increases in mesh size for both square and diamond mesh codends.
- **Improved size-selectivity of fishing gear (14 studies):** Six of 14 replicated, controlled studies (including three paired, one randomized and one randomized and paired) in the Atlantic Ocean[3,8,9,10,16], Mediterranean Sea[12,15], Adriatic Sea[17,23], Aegean Sea[4], English Channel[1], Pacific Ocean[6], Tasman Sea[19] and the Kattegat and Skagerrak[22], found that using a square mesh codend in a trawl net (bottom and pelagic) improved size selectivity for silver hake[8], horse mackerel[9], European hake[9,12,23], axillary seabream[9], poor cod[12,23], greater forkbeard[12], blue whiting[23], discarded fish[15] and three of four commercially targeted fish[10], compared to diamond mesh codends. Five studies[1,3,4,6,19] found no difference in size selectivity between square and diamond mesh codends for Atlantic mackerel[1], long rough dab[3], yellowtail scad and striped

seapike[19], rockfish and flatfish[6], and three of four commercially important bottom fish species[4]. The other three studies[16,17,22] found that the effect of square mesh instead of diamond mesh codends varied with fish body shape (round or flat)[16], and for three of three[22] and five of five[17] roundfish species size selectivity was improved, but not for one flatfish[17,22]. Two of the studies[6,16], where square mesh codends had either no or a varied effect, also found that size selectivity increased with increases in mesh size for both square and diamond mesh codends.

Background

Commercial fishing trawlers conventionally use a net constructed of diamond shaped mesh due to its ability to capture and retain a wide range of sizes and species (Sala *et al.* 2008). However, many of the fish species or individuals are often small, immature, or unmarketable, and will not yet have had the chance to spawn and even if returned to the sea, might not survive (Sala *et al.* 2008). It is difficult for many fish to escape from diamond mesh trawl codends because the mesh openings close under tension during fishing deployments (Isaksen & Valdemarsen (1986). Square shaped mesh however, retains its shape better under strain and maintains a larger size of the gaps in the meshes, potentially allowing greater escape opportunities for smaller fish and invertebrates (Robertson & Stewart, 1986). Square mesh trawl codends instead of diamond mesh codends may therefore increase the escape of small fish from trawl nets and reduce fishing mortality.

Evidence for a similar intervention applied to trawl nets only is summarized under *'Fishing gear modification – 'Rotate the orientation of diamond mesh in a trawl net'*. For interventions describing the effects of different mesh types in fishing gear more generally, but including trawl nets, see *'Fishing gear modification - Use a larger mesh size'*. Evidence of this intervention when used in combination with other interventions to reduce unwanted catch in trawl nets is summarized under '*Fishing gear modification - Fit mesh escape panels/windows to a trawl net and use square mesh instead of diamond mesh codend'* and *'Fit a size-sorting escape grid (rigid or flexible) to trawl nets and use a square mesh instead of a diamond mesh codend'.* Interventions describing the use of sections of square mesh (or large diamond mesh) inserted into diamond mesh nets, see '*Fishing gear modification - Fit mesh escape panels/windows to a trawl net'* and *'Modify the configuration of a mesh escape panel/window in a trawl net'*.

Isaksen B. & Valdermarsen J.W. (1986) Selectivity experiments with square mesh codends in bottom trawls. *ICES C.M.,* 1986/B:28.

Robertson J.H.B. & Stewart P.A.M. (1986) An analysis of length selection data from comparative fishing experiments on haddock and whiting with square and diamond mesh codends. *Scottish Fisheries working Paper,* 9/86.

Sala A., Lucchetti A., Piccinetti C. & Ferretti M. (2008) Size selection by diamond- and square-mesh codends in multi-species Mediterranean demersal trawl fisheries. *Fisheries Research,* 93, 8–21.

A replicated, paired, controlled study in 1990 in an area of pelagic water in the western English Channel, UK (1) found no difference in the size composition (selection) of Atlantic mackerel *Scomber scombrus* in catches from a pelagic trawl with a large square mesh codend, compared to a smaller diamond-mesh codend. Length frequencies of mackerel caught with a 60 mm square mesh codend (range: 8–31 cm, midpoint: 13 cm) were similar to a 40 mm diamond mesh codend (range: 7–32 cm, midpoint: 13 cm). In January–February 1990, mackerel catches were compared from 14 trawl deployments on a commercial fishing vessel: nine with an experimental square mesh codend (60 mm); and five with a conventional diamond mesh codend (40 mm). The experimental codend was 4 m shorter than the conventional codend and had four net panels instead of two. Each trawl type was deployed alternately when mackerel shoals were visible in the water, and all mackerel caught were counted and their lengths measured.

A replicated, paired, controlled study in 1988–1990 of a bottom fishing ground in the Greenland Sea, north Iceland (2) reported that shrimp trawl nets with square mesh codends caught less small, unwanted fish than conventional diamond mesh codends. Data were not statistically tested. In two of two comparisons, catch rates of fish aged <1 year were lower in square mesh than diamond mesh codends for Atlantic cod *Gadus morhua* (square: 2–8 fish/ha, diamond: 6–130 fish/ha) and whiting *Merlangius merlangus* (square: 4–376 fish/ha, diamond: 27–2,472 fish/ha), and in one case for haddock *Melanogrammus aeglefinus* (square: 0–457 fish/ha, diamond: 0–1,245 fish/ha). Catches of one- and two-year-old fish were low but were typically lower in square mesh codends (see paper for data). Overall capelin *Mallotus villosus* catch rates (all ages) were lower in square mesh codends in two of two cases (square: 133–284, diamond: 842–1,104 fish/ha). Target shrimp *Pandalus borealis* catches were lower in square than diamond mesh codends in three of three comparisons. In 1988 and 1990, catches were compared between square mesh codends (36–37 mm) and conventional diamond mesh codends (36–40 mm) in 11 deployments of the two trawl net types towed side by side for 1 h.

A replicated, paired, controlled study in 1988–1990 in two offshore bottom fishing grounds in the Northwest Atlantic Ocean, Canada (3) reported that bottom trawl nets with square mesh codends did not improve size selection of long rough dab *Hippoglossoides platessoides* compared to conventional diamond mesh codends at three different mesh sizes. Data were not statistically tested. The length at which plaice had a 50% chance of escape was lower in square mesh codends at all three mesh sizes tested (130 mm: 31 cm, 140 mm: 31 cm, 155 cm: 32 cm) than diamond mesh (130 mm: 31 cm, 140 mm: 38 cm; 155 cm: 38 cm) and was reported to increase marginally with increasing mesh size. Catches from square and diamond mesh codends of three different mesh sizes were compared during three experimental trials on the Scotian Shelf (140 mm mesh, 31 hauls) and Grand Bank (155 mm mesh, 29 hauls) in October 1988 and on the Grand Bank in March 1990 (130 mm mesh, 32 hauls). All hauls were done using a standard bottom trawl net modified with twin codends: each test codend (square or diamond) on one side towed with a small mesh (39 mm) control codend on the other (sides rotated during each trial). Codend catches from each haul were sorted and plaice were counted, and their lengths measured.

A replicated, randomized, controlled study in 1993–1994 in two seabed areas in the Aegean Sea, Greece (4, same experimental set-up as 5 and 7) reported that a bottom trawl with a square mesh codend improved the size selectivity and escape rate of only one of four commercially important bottom fish species, compared to a diamond mesh codend of the same mesh size. Results were not statistically tested. The estimated length at which fish had a 50% chance of escape was greater in 20 mm square mesh codends than 20 mm diamond mesh codends for European hake *Merluccius merluccius* (15.1 vs 13.8 cm) and both were greater than the 14 mm diamond mesh (4.2 cm); but smaller for blue whiting *Micromesistius poutassou* (17.0 vs 21.2 cm), poor cod *Trisopterus minutus capelanus* (11.9 vs 13.7 cm) and four-spot megrim *Lepidorhombus boscii* (8.5 vs 10.3 cm) (selectivity for these species could not be estimated for the 14 mm diamond mesh codend). The proportion of fish retained in the trawl versus those that escaped was lower in square mesh codends for hake (square: 0.26, diamond: 0.35), but was higher for blue whiting (square: 0.61, diamond: 0.29), poor cod (square: 0.31, diamond: 0.18) and megrim (square: 0.90, diamond: 0.66). Experimental trawl deployments were conducted in the Trikeri Channel in October 1993 (5 stations) and the North Euboikos Gulf in March 1994 (seven stations). A trawl net was randomly assigned either a 20 mm square mesh codend or a 14 mm (the size currently used commercially) or 20 mm diamond mesh codend, and towed for 45–60 min at depths between 73–210 m. Each codend was deployed for 12 hauls. Small mesh (10 mm) covers over the codend sampled the escaping fish catch. Fish from the codend and cover were identified and counted, and their lengths measured.

A replicated, randomized, controlled study in 1993–1994 in two seabed areas in the Aegean Sea, Greece (5, same experimental set-up as 4 and 7) found that a bottom trawl net with a square mesh codend did not allow more unwanted individuals and higher number of species (fish and invertebrates) to escape compared to a diamond mesh codend of the same mesh size. In two of two years, the average number of individuals (fish and invertebrates) and species escaping from the codend was similar between square and diamond mesh (individuals, square: 1,653–6,100/h, diamond: 1,486–8,167/h; species, square: 12–15/h, diamond: 12–16/h). Experimental trawl deployments (using the same experimental set-up as Petrakis & Stergiou, 1997) were conducted in the Trikeri Channel in October 1993 (5 stations) and the North Euboikos Gulf in March 1994 (seven stations). A trawl net was randomly assigned either a 20 mm square mesh codend or 20 mm diamond mesh codend (12 hauls each codend), and towed for 45–60 min at depths between 73–210 m. Small mesh (10 mm) covers over the codend sampled the escaping fish catch. All individuals caught in the covers were identified and counted.

A replicated, randomized, paired, controlled study in 1988–1990 in fishing grounds in the Pacific Ocean off the west coast USA (6) found that bottom trawls fitted with a square mesh codend did not typically improve the selectivity or reduce the catch of unwanted small, rockfish and flatfish species compared to diamond mesh codends, but increasing the mesh size did, for both designs. The length at which half of fish were likely to escape capture was higher in square mesh codends than diamond mesh codends of the same mesh size for two of five rockfish but none of four flatfish (see paper for individual data – not statistically tested). Increasing the mesh sizes retained fewer undersized fish in both codend types: for four of four rockfish and three of four flatfish in square mesh increased from 114 mm to 127 mm; and for five of five rockfish and three of four flatfish in diamond mesh increased from 114 mm to 127–140 mm (data presented as selectivity curves). In 1988–1990 the West Coast Groundfish Mesh Size survey tested experimental diamond mesh codends with mesh sizes of 76 (chosen as the 'standard' for analysis), 114, 127 and 140 mm and square mesh codends of 114 mm and 127 mm. Codends were towed in randomized blocks of two or three codends at a time during each fishing season by commercial trawling vessels, totalling 493 deployments.

A replicated, randomized, controlled study in 1993–1994 in two seabed areas in the Aegean Sea, Greece (7, same experimental set-up as 4 and 5) found that found that a bottom trawl net with a square mesh codend retained more fish overall than a diamond mesh codend of the same mesh size but this varied with species shape and size, and both retained fewer fish compared to a diamond mesh codend of smaller mesh size. The average proportion of retained versus escaped catch (for 36 fish species and 1 invertebrate) was higher for the square mesh than diamond mesh of the same size, but lower than smaller diamond mesh (square: 0.63, diamond: 0.49, small diamond: 0.93 retained). In addition, there were differences in the retained proportions of individual fish species between the square and diamond mesh codends of the same mesh depending on fish shape (round- or flatfish) and size (small or large). Experimental trawl deployments were conducted in the Trikeri Channel in October 1993 (5 hauls) and the North Euboikos Gulf in March 1994 (seven hauls). A trawl net was randomly assigned either a 20 mm square mesh codend or a 14 or 20 mm diamond mesh codend, and towed for 45–60 min at depths between 73–210 m. Small mesh (10 mm) covers over the codend sampled the escaping fish catch. All individuals caught in the covers and codends were identified and counted.

A replicated, paired, controlled study in 1994–1995 in two offshore areas of seabed in the North Atlantic Ocean, Canada (8) found that square mesh codends improved the size-selectivity of a trawl net for silver hake *Merluccius bilinearis*, compared to diamond mesh codends. The estimated length at which 50% of hake were predicted to escape was higher in square mesh codends than diamond, and between square meshes was higher in the larger mesh size (square, 60 mm mesh: 26 cm, 55 mm mesh: 23 cm; diamond, 60 mm mesh: 16–19 cm). Data were collected on two chartered commercial inshore otter trawlers during five experimental surveys in the Emerald and LaHave basins (central Scotian Shelf) between July 1994 and March 1995. During each survey, one experimental codend (one survey each of 55 or 60 mm square mesh, and three surveys of 60 mm diamond mesh with or without a 89 mm chafer section – see paper for gear specifications) was towed on one boat parallel to a small mesh control codend (19 mm) on the other, for a total of 98 valid paired hauls in 180–265 m depth. In all experiments, a size-sorting escape grid was installed in front of the codend. Silver hake catches were subsampled for weight, and fish length (snout to the middle of the tail fin) recorded.

A replicated, controlled study in 1993 in a fished area of seabed in the Atlantic Ocean off the south coast of Portugal (9) found that a square mesh codend improved the size-selectivity of a crustacean trawl net for three of three non-target fish, compared to diamond mesh codends of similar mesh size. The estimated length at which fish had a 50% chance of escape was greater with the square mesh than diamond meshes of increasing sizes for blue whiting *Micromesistius poutassou* (square: 30 cm, diamond: 23–27 cm). For horse mackerel *Trachurus trachurus*, the 50% escape length was greater with square mesh than the two smallest diamond mesh codends (square: 22 cm, diamond: 18–20 cm), but similar to the larger diamond mesh codend of 70 mm (22cm). In addition, for European hake *Merluccius merluccius,* the proportions of escapees below the minimum landing size relative to those retained were improved in the square mesh compared to the two smallest diamond meshes (see paper for data). However, since only very small proportions were retained overall for both the square and the largest diamond mesh, their size-selectivity was not calculable. Data were collected on two surveys in March/April and May 1993 from 133 deployments of a crustacean trawl (1 h) by a research vessel in depths of 152–706 m. A square mesh cod end of 55 mm mesh size (24 hauls), and three diamond mesh cod ends of 55 mm (41 hauls), 60 mm (33 hauls) and 70 mm (35 hauls) were tested. Covers fitted over each codend collected fish escaping through the meshes. Fish in both the codend and cover catches were separately identified, weighed, and total lengths measured.

A replicated, controlled study in 1992 in a fished area of seabed in the Atlantic Ocean off the southwest coast of Portugal (10) reported that changing the configuration of mesh in a bottom trawl net to square from diamond resulted in lower retention and improved size selection of three of four commercial fish species. Across all hauls, the square mesh codend released more smaller and/or undersized individuals of European hake *Merluccius merluccius*, blue whiting *Micromesistius poutassou* and horse mackerel *Trachurus trachurus* than diamond mesh codends, but it was similar for four spot megrim

Lepidorhombus boscii (data presented as size frequencies and selectivity curves). The length at which fish have a 50% chance of escape was higher in square mesh for hake (square: 25 cm, diamond: 17–19 cm). Almost all blue whiting escaped from the square mesh codend and all horse mackerel were retained in diamond mesh codends (compared to 40% escape in square mesh) meaning estimates of selectivity could not be calculated. Catch comparison surveys were done by a research vessel in August 1992 using a square mesh codend of 65 mm mesh size (10 hauls) and diamond mesh codends of mesh sizes of 65 mm (13 hauls), 70 mm (18 hauls) and 80 mm (19 hauls). Deployments were of 1 h, at 3.5 kn and in depths of 200–400 m. Covers fitted over each of the codends sampled fish escaping through the meshes. Codend and cover catches were weighed. All total lengths of hake and megrim were measured, and mackerel and whiting lengths sub-sampled.

A replicated, randomized, paired, controlled study in 2002 in a seabed area in the Clarence Estuary (Tasman Sea), New South Wales, Australia (11) found that square mesh codends fitted to prawn trawls reduced the catch numbers of unwanted young fish of three of six commercially important species compared to diamond mesh codends. Average catch numbers of non-target southern herring *Herklotsichthys castelnaui*, Tasmanian whitebait *Lovettia sealii*, and pink-breasted siphonfish *Siphamia roseigaster* were lower in square mesh than diamond mesh codends (square: 0–9 fish, diamond: 17–75 fish) and were similar for catfish *Siluriformes*, Ramsey's perchlet *Ambassis marianus*, and silver biddies *Gerreidae* (square: 2–4 fish, diamond: 2–9 fish). In March 2002, experimental fishing was done on commercial prawn-trawl fishing grounds in Lake Woolooweyah using a commercial trawler. One of four designs of trawl codend were deployed on one side of a twin trawl, paired on the other side with small mesh control codends, all with Nordmøre escape grids (20 mm bar spacing): two square mesh codends (20 mm mesh, one tapered and one non-tapered), and two diamond mesh codends (40 mm, 100 or 200 meshes circumference). Twenty replicate hauls of each test codend/control were done. All catches were sorted and counted separately.

A replicated, controlled study in 2005 in two areas of seabed in the Mediterranean Sea off eastern Spain (12) found that square mesh instead of diamond mesh codends improved the size-selectivity of commercially important European hake *Merluccius merluccius*, poor cod *Trisopterus minutus* and greater forkbeard *Phycis blennoides* in a multi-species bottom trawl fishery. Across all hauls, the selection length (the length at which 50% of fish are predicted to escape) was higher in the square mesh codend for hake (square: 16 cm, diamond: 10 cm), poor cod (square: 13 cm, diamond: 9 cm) and forkbeard (square: 15 cm, diamond: 10 cm). Commercial fishing deployments with both square and diamond mesh codends (40 mm) were conducted in July 2005 on the continental shelf (100 m, 19 hauls) and upper slope (400 m, 9 hauls) of the Catalan Sea. Tow duration was 15–157 minutes. A small mesh cover (15 mm) over each codend sampled escaped fish.

A replicated, paired, controlled study in 2004 in two seabed areas in the South Pacific Ocean off New South Wales, Australia (13) found that square mesh codends in a mixed species bottom trawl fishery reduced the catches of discarded whiting *Sillago* spp. compared to conventional diamond mesh codends. Data were reported as statistical model results. Results varied between vessels, and in one of three cases the number and weight of total discarded whiting was lower in square mesh codends (35 and 41 mm) than diamond (41 mm/150), but there were no differences between codends for retained total whiting, or species individual categories. For a second vessel, there were no clear reductions in any whiting catches between a 35 mm square mesh and diamond mesh (41 mm/150), but a 41 mm square mesh had lower weight of total retained whiting and lower number and weights of total and retained stout whiting *Sillago robusta*. For the third vessel, there were no main differences in whiting catches between square (31 mm) and diamond mesh (41 mm/100) codends. In addition, square mesh codends improved selection for stout whiting compared to diamond, and the length at which 50% of fish are predicted to escaped increased with increasing size of the square mesh (35 mm: 14–15 cm, 41 mm: 17–18 mm. Catch data were collected on three commercial prawn trawlers, fishing with the two outer nets of a triple trawl gear configuration, in April-December 2004. Seventy-one paired trawl deployments were carried out in 27–51 m depth using one of five test codends on one side - two square mesh codends (nominal 35 and 45 mm mesh), and three diamond mesh codends (two 41 mm mesh of 100 and 150 mesh circumference and one 45 mm mesh) - and a small mesh (24 mm) control codend on the other. All trawl nets also included a square mesh escape panel. See original study for gear details. The weights, numbers and total lengths of total, retained and discarded stout and red spot whiting *Sillago flindersi* were recorded.

A replicated, controlled study in 2002–2003 of deep-water prawn fishing grounds in the Mediterranean Sea, Spain (14, same experimental set-up as 15) found that a square mesh codend reduced the amount of discarded fish catch, compared to a conventional diamond mesh codend. The proportion (by weight) of discarded non-commercial species was lower in the square mesh codend (3–11%, of which 80–93% were fish) compared to the diamond mesh codend (7–28%, of which 90–98% were fish), and was similarly decreased for discarded commercial species (square: 2–7%, of which 59–97% were fish; diamond: 7–17%, of which 45–99% were fish). In addition, no differences in commercial retained catch were found between mesh types and overall, the catch composition varied with depth and season. The total catch (weight) comprised fish (teleosts 55%, elasmobranchs 14%), crustaceans (28%), and cephalopods (6%). Catch comparison data were collected by commercial bottom trawler on a main crustacean fishing ground between 251–737 m depths, south of Mallorca. A total of 19 bottom trawl deployments each of square and diamond mesh codends (both 40 mm mesh) were done in September-October 2002 (18 hauls) and May-June 2003 (20 hauls). Deployments were 4.5 h at 2.5 knots. A small mesh (20 mm) cover over the codends sampled the escaping catch. All fish were identified, counted, and length measured.

A replicated, controlled study in 2002–2003 in two areas of seabed on the continental shelf in the Mediterranean Sea, Spain (15, same experimental set-up as 14) found that using a square mesh instead of diamond mesh codend in a multi-species bottom trawl fishery reduced the amount of fish discarded in deeper but not shallower shelf areas, and size-selectivity was improved in both areas. Average catch biomass of total discarded fish (80–90% of which were non-commercial species) was lower in the square mesh codend on the deep shelf (square: 10, diamond: 20 kg/30 min) and similar between mesh shapes on the shallow shelf (square: 6, diamond: 10 kg/30 min). The length at which 50% of fish are predicted to escape, where reported, was higher in the square mesh in both shallow and deep areas for all fish (square: 7–29 cm, diamond: 2–19 cm; see paper for species individual data). Fishing deployments were conducted from a commercial trawler in September–October 2002 and May–June 2003 (same experimental set-up as Guijarro & Massuti, 2006), on the shallow (50–78 m, 12 hauls) and deep (147–189 m, 12 hauls) continental shelf off the Balearic Islands. Twelve hauls were carried out in each area: 6 each of a square and diamond mesh codend (both 40 mm mesh size). A small mesh (20 mm) cover installed over the codends sampled catch escaping through the meshes.

A replicated, controlled study in 2003 of a fished area of seabed in the northwest Atlantic Ocean off New Hampshire, USA (16) found that the effect of using square mesh instead of diamond mesh codends on the size-selectivity of bottom trawl nets for five important commercial fish species depended on body shape (roundfish or flatfish), but for both square and diamond codends, selectivity increased with larger mesh sizes. For cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* there were no differences in the selection length (the length at which 50% of fish are predicted to escape) between square and diamond mesh of the same mesh size (cod, square: 59–69 cm, diamond: 59–66 cm; haddock, square: 54–57 cm, diamond: 55–61 cm); but for three flatfish, the selection lengths were smaller in square mesh codends (long rough dab *Hippoglossoides* platessoides, square: 33–35 cm, diamond: 39–40 cm; yellowtail flounder *Limanda ferruginea*, square: 34–38 cm, diamond: 40–42; witch flounder *Glyptocephalus* cynoglossus, square: 36–40 cm, diamond: 43–46 cm). For all species, an increase in selection length was found with increasing mesh size in both diamond and square mesh (see paper for individual data by species and codend). Catch data was collected in May–July 2003 from 86 fishing vessel deployments in the western Gulf of Maine (33–142 m depths). Five codends were tested: two square mesh (165 and 178 mm), and three diamond mesh (152, 165 and 178 mm). The five codends were tested in a preselected random order, each for up to six consecutive tows, for between 14–20 hauls. A small mesh cover over each codend sampled escaped fish. Codend and cover catches were counted and weighed by species, and fish total lengths measured (sub-sampled where necessary).

A replicated, controlled study in 2004 in one shallow inshore and one deeper offshore seabed area in the Adriatic Sea, Italy (17) found that for five roundfish species, but not one flatfish species, using a square mesh codend improved the size selectivity of a bottom trawl net compared with a diamond mesh codend. Overall, the length at which 50% of fish are predicted to escape was greater in the square mesh codend for European hake *Merluccius merluccius* (square: 14 cm, diamond: 8 cm), red mullet *Mullus barbatus* (square: 11 cm, diamond: 8 cm), common pandora *Pagellus erythrinus* (square: 10 cm, diamond: 8 cm), Mediterranean horse mackerel *Trachurus mediterraneus* (square: 13 cm, diamond: 10 cm) and poor cod *Trisopterus minutus capelanus* (square: 11 cm, diamond: 8 cm), but was lower for one flatfish, scaldfish *Arnoglossus laterna* (square: 8 cm, diamond: 8 cm). Fishing surveys were done by research vessel on two fishing grounds in the Central Adriatic: in August–September 2004 (15–21 m depth, 5nm off Ancona), and in September–October 2004 (70 m depth, Western Pomo pit). Two trawl codends with the same mesh size (38 mm) but different mesh configuration (square and diamond mesh) were fished daily and alternately on the same trawl for a total of 48 deployments (21 shallow, 27 deeper). A small mesh cover (20 mm) attached over each codend collected the escaping fish catch. Catches in both the codends and covers were sampled by species and fish total length.

A replicated, paired, controlled study in 2007 of two fished areas of seabed in the English Channel off southwest England, UK (18) found that beam trawl nets with square instead of diamond mesh codends, reduced the amount of discarded finfish catch. Across both sampling areas, the square mesh codends caught 30–52% fewer discarded finfish than the diamond (square: 1,496–1,830 fish, diamond: 2,124–3,836 fish). By individual fish species/groups, total numbers of four (all roundfish) of the nine most numerous were reduced in one or both areas by 18–80%, while for the rest (all flatfish), there were no differences between codend types for four and one was lower (by 56%) in the square mesh in the inshore area only. In addition, the retained finfish catches were similar between codend types in both areas (square: 943–985 fish, diamond: 948–1,005 fish). Catch comparison trials were done at two separate bottom fishing grounds off the south west coast of England by two commercial beam trawl vessels during 6 d sampling trips in July and August 2007. A total of 24 deployments were made of two beam trawl nets towed simultaneously: one an 80 mm square mesh codend, and one a standard 80 mm diamond mesh codend (see paper for specifications). Catches from both trawl nets were kept separate and divided into discarded and retained portions. Discarded finfish and all retained fish were identified, and their total lengths measured (sub-sampled where necessary).

A replicated, controlled study in 2008–2009 of an area of seabed in an estuary off the Tasman Sea, Australia (19) found that using a square mesh codend in a squid trawl net did not reduce the overall amount of discarded catch (fish and invertebrates), or improve the size selectivity for yellowtail scad *Trachurus novaezelandiae* and striped seapike *Sphyraena obtusata*, compared to a diamond mesh codend. Average numbers of total discarded catch (fish and invertebrate species combined – see paper for species caught) were similar for each of two sizes of square mesh codend (29 and 32 mm) compared to a 41 mm diamond mesh codend (29 mm square: 715 ind; 32 mm square: 250 ind; diamond: 300–500 ind). In addition, no statistical differences between square and diamond mesh codends were found in the length at which 50% of fish are predicted to escape for two fish species caught in the covers in sufficient quantities: yellowtail scad (square: 13 cm; diamond: 11–12 cm); and striped seapike (square: 20 cm; diamond: 15 cm). Catches from three different codends (29 and 32 mm square mesh, and 41 mm diamond mesh) were compared on a single-rigged trawler on a commercial squid *Loliginidae* spp. trawl ground in the Hawkesbury River estuary, in December 2008 and May 2009. All codends also had a 42 mm square mesh escape panel fitted in front. A total of between 10 and 12 deployments (75 min) of each codend were done. A small mesh (18 mm) hooped cover attached over each codend sampled the escaping catch.

A replicated, paired, controlled study in 2009 of an area of seabed in the Aegean Sea, Turkey (20) found that the short-term survival of two of six fish species after escaping from bottom trawls was higher in square mesh codends compared to diamond mesh codends. Overall, average survival rate was greater in square than diamond mesh codends for escaped red mullet *Mullus barbatus* (square: 95% of 950 fish; diamond: 81% of 225 fish) and blotched picarel *Spicara maena* (square: 97% of 460 fish; diamond: 91% of 174 fish). For annular seabream *Diplodus annularis* (82 fish) and common pandora *Pagellus erythrinus* (46 fish), survival rate was 100% for both codend types. In addition, average brown comber *Serranus hepatus* post-escape survival was 97% (of 332 fish) and 95% (of 126 fish) for square and diamond mesh codends, whilst all 355 scaldfish *Arnoglossus laterna* did not survive. For all species, most mortality occurred in the first 48 h after escape. Six, 15-min experimental bottom trawl deployments were done by research vessel off the southern coast of Yassica Island, Izmir Bay, in October 2009: three using a square mesh and three a diamond mesh codend (both 40 mm). Small mesh (24 mm), hooped detachable covers fitted over each codend collected escaped fish and at the end of each deployment were detached, sealed, and deployed on the seabed. Fish were fed and survival monitored in the anchored covers for seven days by divers.

A replicated, paired, controlled study in 2009 in bottom fishing grounds in the Bristol Channel, UK (21) reported that bottom trawl nets fitted with a square mesh codend caught fewer discarded fish compared to a standard diamond mesh codend, and the overall survival likelihood of skate *Rajidae* spp. post-capture was improved. Data were not statistically tested. Overall numbers of discarded fish in the 100 mm square mesh codend were 68% lower than the 80 mm diamond mesh codend (square: 2,241 fish, diamond: 7,056 fish), and ranged between 25% to 100% for individual species/groups (see paper for data). The proportion of skate given a good initial 'health' score after capture (equal to 86% chance of survival) as a proxy for survival likelihood) was 47% in the square mesh codend and 25% in the diamond mesh codend. Catch data was collected in June/July 2009 on a commercial twin-rigged bottom trawler at 35–65 m depth. Sixteen paired trawl deployments (3–5 kn) were done with an experimental 100 mm square mesh codend towed simultaneously with a conventional 80 mm diamond mesh codend. Separate assessment of the post-capture visual condition and survival of 278 small-eyed skate *Raja microocellata* was used to determine a three-point 'health' scale as an indicator of survival. The scale was used to assess the health of individuals of five skate species (see paper for details) as the nets came aboard, 358 skate from the square mesh and 754 from the diamond mesh codend.

A replicated, controlled study in 2006–2007 in two fished areas of seabed in the Kattegat and the Skagerrak, Denmark (22) found that a standard square mesh codend improved the size-selectivity of a bottom trawl net for three roundfish species, but not one flatfish species, compared to a standard diamond mesh codend. Overall, the length at which 50% of fish were predicted to escape was greater in the square mesh compared to the diamond mesh codend for roundfish: Atlantic cod *Gadus morhua* (26–27 cm vs 15–17 cm), haddock *Melanogrammus aeglefinus* (26 cm vs 15 cm) and whiting *Merlangius merlangus* (33 cm vs 18 cm); but it was lower for plaice *Pleuronectes platessa* (square: 14–15 cm, diamond, 19–20 cm). Catch comparison trials were done on multi-species fishing grounds (Norway lobster *Nephrops norvegicus*, cod and plaice) on two commercial twin-trawl vessels in September 2006 (18 deployments) and August 2007 (6 deployments). Two codends were tested, towed simultaneously each haul, and interchanged between left and right sides: a commercial square mesh (70 mm) and a commercial diamond mesh (90 mm). Hauls were 1–4 h at 32–184 m depth. Small mesh covers (36 mm) were attached over each codend and collected fish escaping from the upper and lower parts of the codend in separate compartments.

A replicated, controlled study in 2005 in one area of muddy-sandy seabed in the Adriatic Sea, Italy (23) found that a square mesh codend improved the size selectivity of a prawn trawl net for European hake *Merluccius merluccius*, blue whiting *Micromesistius poutassou* and poor cod *Trisopterus minutus capelanus*, compared to diamond mesh codends of standard and large circumferences. Across both surveys, the estimated lengths at which 50% of fish are predicted to escape were greater in hauls with the square mesh codend than the two diamond mesh codends for three commercially important species: hake (square: 12–16 cm; diamond: 8–11 cm), blue whiting (square: 14–18 cm; diamond: 11–15 cm), and poor cod (square: 10–13 cm; diamond: 6–10 cm). Catch comparison trials were done during two research vessel surveys in the Western Pomo pit (210 m depth; a Norway lobster *Nephrops norvegicus* fishing ground) in May and September 2005. Three codends were tested, all nominal 40 mm mesh size: a square mesh codend (70 meshes circumference); and two diamond mesh codends, one of conventional circumference (280 meshes) and one larger (326 meshes). Over the two surveys a total of 20 deployments were done with the square mesh codend, and 19 and 13 deployments with the standard and large diamond mesh codends, respectively. A cover attached over each codend sampled the catch escaping through the meshes.

A replicated, controlled study in 2008–2009 in bottom fishing grounds in the Pacific Ocean, off Chile (24) found that the effect of crustacean trawl nets fitted with square mesh codends on reducing discarded fish catch, varied with mesh size as well as mesh configuration, compared to a reference diamond mesh codend. In one of two target fisheries for crustaceans, escape rates (by weight) of Chilean hake *Merluccius gayi gayi* and bigeye flounder *Hippoglossina macrops* (the two main non-target fish species) were higher in both 70 mm square mesh and diamond mesh (D70) codends than the 56 mm diamond (D56) mesh codend (hake, square: 36%, D70: 16%, D56: 0%; flounder, square: 28%, D70: 17%, D56: 1%). For the other target crustacean fishery, main non-target fish escape rates (by weight) were higher in a 56 mm square mesh codend than a 56 mm diamond mesh codend for eelpout *Zoarcidae* spp. (99 vs 26%) only, and were similar between the codends for: Chilean hake (3 vs 0%), aconcagua grenadier *Coelorinchus aconcagua* (17 vs 3%) and cardinalfish *Apogonidae* spp. (19 vs 4%). However, they were all higher in a 70 mm diamond mesh codend than the 56 mm diamond mesh codend. Retained and escaped catches were compared between four codends of different mesh size (56 or 70 mm) and mesh configuration (square or diamond), and a reference 56 mm diamond mesh codend (see paper for gear specifications). In total, 84 trawl deployments were made in December 2008 in traditional crustacean fishing grounds using commercial vessels. A small mesh (32 mm) cover attached over each codend during deployment collected the escaped catch.

A replicated, paired, controlled study (year not stated) of a fished area of seabed in the Tasman Sea, Australia (25) found that a square mesh codend reduced the amounts of discarded total catch (fish and invertebrates) in two target prawn trawl fisheries compared to commercial diamond mesh codends, and the effect on individual categories of discarded fish catch varied between species or the target fishery. Overall numbers of total discarded catch (fish and invertebrates) were reduced by the square mesh codend in both target prawn fisheries, by 48% and 77% (square: 69–382 ind/h, diamond: 287–661 ind/h). For the eastern king prawn *Melicertus plebejus* fishery, unwanted or undersized catches by number of three of the seven main discarded fish species/categories were reduced in the square mesh codend (by 59–95%), one was higher, and the rest were similar between square and diamond mesh codends. In the fishery targeting school prawns *Metapenaeus macleaya*, unwanted fish catch of four of the six main discard species/categories were 84–99% lower in the square mesh codend, while there was no difference for the other two between codend types (see paper for individual data). Catch data were collected by observers on seven commercial prawn trawlers operating from four ports off New South Wales: from 42 paired deployments targeting eastern king prawns (41–68 m depth) and 13 targeting school prawns (6–10 m). Each vessel was supplied with a 35 mm square mesh codend with a composite square mesh escape panel to test against the different diamond mesh codends (each with industry-designed square mesh escape panels) being used on each vessel (see paper for gear details). The square mesh codend was towed simultaneously with the industry standard codend on the outer trawls of standard triple-gear trawl configurations. The year the study took place was not reported.

A replicated, randomized, paired, controlled study in 2002 of a fished area of seabed in the Coral Sea, Australia (26) found that a prawn trawl net with a square mesh codend reduced the overall amount of unwanted non-target catch (fish and invertebrates) compared to a conventional diamond mesh trawl, and the effect on individual fish species varied. Average catch rates by weight of total unwanted catch (fish and invertebrates, seven fish species accounting for 50% by weight) was lower in square mesh compared to diamond mesh codends, both with and without grids (square: 796–908 g/ha, diamond mesh: 1,114–1,150 g/ha). By individual fish species, five of the 40 species analysed had lower catch rates (three by over 90%) in square mesh than diamond mesh codends, without grids (square: 1–115 g/ha, diamond: 5–134 g/ha), one was higher (square: 29 g/ha, diamond: 60 g/ha) and there were no differences between codend types for the rest (see paper for spceis individual data). Over 10 days in July 2002, data were collected from 65 paired trawl deployments on deepwater eastern king prawn fishing grounds off the southeast Queensland coast. Four codends were tested: a 48 mm square mesh with and without a rigid escape grid (turtle excluder device), and a 45 mm diamond mesh codend with and without a grid. Codend designs were randomly assigned to one of the two outer trawl nets of a triple-rigged trawl every 12 hauls and towed simultaneously.

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2.51 Rotate the orientation of diamond mesh in a trawl net

- **Six studies** examined the effects of rotating the orientation of diamond mesh in a trawl net on marine fish populations. Three studies were in the Baltic Sea[2,3,5] (Denmark), and one study was in each of the Kattegat and Skagerrak[1] (northern Europe), the Aegean Sea[4] (Turkey) and the North Sea[6] (Belgium/UK).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (6 STUDIES)

- **Improved size-selectivity of fishing gear (6 studies):** One review study in the Kattegat and Skagerrak[1] and four of five replicated, controlled studies (one paired) in the Baltic Sea[2,3,5], Aegean Sea[4], and North Sea[6] found that turning the orientation of diamond mesh in trawl codends by 90° resulted in better size selection of cod[1,2,3], red mullet and common pandora[4], and round-bodied fish species[6], but not of plaice[3], annular sea bream[4], and flatfish species[6], compared to standard orientation of diamond mesh in trawl codends. The other study[5] found that turned mesh instead of standard diamond mesh trawl codends did not improve the size selectivity of cod, plaice and flounder.

Background

Trawl fisheries are a common type of fishing practice around the world. The codend of a trawl net is designed to retain fish and often leads to large numbers of unwanted fish being caught. This can be reduced by modifying the codend design to increase the size selectivity of the gear. One way this might be done is to change the orientation of the meshes of the net. Standard trawl codends are constructed from diamond shaped meshes. During deployment the diamond meshes close under tension and the size of the opening through which fish can escape is drastically reduced. Rotating or turning the orientation of diamond mesh involves the knots of the meshes being tied in such a way that the mesh is turned through 90 degrees to the water flow (often referred to as T90 mesh). This results in the meshes being held more open under tension and maintains a larger gap through which fish can escape. This may in turn help to reduce the catches of unwanted smaller fish.

Note: Rotated, or T90, diamond mesh is not to be confused with nets made of square mesh, which consist of diamond mesh turned through 45 degrees to the water flow to create a square shape ensuring the meshes remain almost fully open (see *'Fishing gear modification – 'Use a square mesh instead of a diamond mesh codend in a trawl net'*.).

Evidence for a similar intervention applied to trawl nets only is summarized under *'Fishing gear modification – 'Use a square mesh instead of a diamond mesh codend in a trawl net'*. For interventions describing the effects of different mesh types in fishing gear more generally, but including trawl nets, see *'Fishing gear modification - Use a larger mesh size'*.

A review in 2010 of 10 studies of various trawl gear modifications in bottom fishing grounds (one of which assessed rotating diamond mesh) in the Kattegat and Skagerrak, northern Europe (1) reported that rotating the diamond mesh in a prawn trawl net codend by 90° improved the size selectivity of cod *Gadus morhua* compared to a standard diamond mesh codend of the same mesh size. Data were not statistically tested. The length at which cod had a 50% chance of escaping was 32.2 cm in a turned diamond mesh codend and 23.7 cm in a standard diamond mesh codend (both 99 mm mesh size). The review summarized data from 10 studies between 2005–2010 on the effects on cod catch and size selectivity of various modifications to trawl nets targeting Norway lobster *Nephrops norvegicus.* One of the 10 studies identified provided size selectivity data for diamond mesh codends with and without rotated mesh from 16 trawl deployments for each codend type (original study written in Danish).

A replicated, controlled study in 2009 of bottom fishing grounds in the Baltic Sea, Denmark (2) found that turning the orientation of diamond mesh netting in the codend of a trawl net by 90° improved size selectivity for cod *Gadus morhua* compared to the standard mesh orientation. In two of two trials, the length at which cod had a 50% chance of escaping was greater in turned diamond mesh trawl nets (39–42 cm) than standard trawl nets (34–39 cm). Data were collected by research vessel surveys on fishing grounds south of the island of Bornholm in October 2009. Two trawl codends of netting made with the diamond meshes turned 90° relative to the standard (one with 46 and one with 91 meshes circumference) were tested against two standard diamond mesh nets (44 and 92 meshes circumference). Eight deployments of the 90°/46 mesh circumference and seven deployments of each of the 90°/91 mesh circumference and both the standard trawl nets were made.

A replicated, controlled study in 2011 of an area of seabed in the western Baltic Sea, Denmark (3) found that rotating the diamond mesh of trawl net codends by 90° increased the size selectivity for cod *Gadus morhua*, but not plaice *Pleuronectes platessa*, compared to standard diamond mesh, and was influenced by twine number. The length at which cod had a 50% chance of escape was higher with turned diamond mesh than standard diamond mesh at any given twine thickness (2–8 mm), and for both of the turned mesh orientations decreased with increasing twine number (turned, single: 39–42 cm, standard: 31–42 cm; turned, double: 29–41 cm, standard: 21–41 cm). For plaice, 50% escape likelihood was lower with turned meshes at all twine thicknesses and number (turned, single: 20–24 cm, standard: 24–25 cm; turned, double: 17–24 cm, standard: 24–25 cm). Data were collected from 43 experimental trawl deployments (90–180 min, 32–

49 m depth) in the Arkona Basin in March–April 2011. Twelve codends were tested: six with diamond mesh turned by 90°, and six with standard mesh and either single or double twine at one of four twine thicknesses (3, 4, 6 or 8 mm)(see original paper for specifications). Each of the 12 codends was fished alternately, one at a time, from the same trawl. Covers attached over each codend collected fish escaping through the meshes. The lengths of cod and plaice in the codends and covers were measured to the nearest cm.

A replicated, controlled study of an area of seabed in a coastal bay in the Aegean Sea, off Turkey (4) found that rotating the direction of diamond mesh in a trawl codend by 90° increased the size selectivity of red mullet *Mullus barbatus* and common pandora *Pagellus erythrinus*, but not annular sea bream *Diplodus annularis*, compared to the standard diamond mesh direction. The length at which red mullet and common pandora had a 50% chance of escape was larger in codends with turned diamond mesh of three mesh sizes compared to standard diamond mesh (mullet, turned: 12–18 cm, standard: 9–15 cm; pandora, turned: 10–13 cm, standard: 9–11 cm), and there was no difference for annular sea bream at all mesh sizes (9–12 cm). Trials were done by research vessel in Izmir Bay during several periods between December to May. Three bottom trawl codends with diamond mesh turned by 90° were tested against two codends of standard diamond mesh orientation. A total of 61 valid deployments of 30 min were made: 13–17 hauls of turned diamond mesh codends of each of 40, 44 and 50 mm mesh size; and 10–11 standard diamond mesh codends, each of 40 mm and 50 mm mesh size. Al codends were attached to the same trawl net. Codend catches were sorted by species and fish length recorded. The year the study took place was not reported.

A replicated, controlled study in 2008–2010 on fishing grounds in the western Baltic Sea, Denmark (5) found that turning the mesh orientation in diamond mesh trawl codends by 90 degrees did not improve the size selectivity for cod *Gadus morhua*, plaice *Pleuronectes platessa* and flounder *Platichthys flesus*, compared to standard diamond mesh orientation, but was influenced by twine type and codend circumference. Data were reported as statistical model results. For all three species, there was no effect of codend mesh orientation (diamond turned by 90° or standard diamond) on size selectivity between all codends tested. However, size selectivity was improved for all three species by twine type (higher in codends made from the flexible compared to the standard polyethylene twine) and by reducing the codend circumference for cod, but not for plaice and flounder. Five codends made from a flexible, strong twine (Dyneema) of a similar mesh size (110 mm) and twine thickness (2.5 mm), but different mesh orientation (turned 90° or standard), codend circumference (44 or 48 meshes), and number of twines (single or double), were tested during two experimental fishing trials in the Arkona Sea in September 2008 and March 2010. Two further turned mesh codends made from standard 5 mm single twine netting were also tested. Selectivity data for cod >33 cm only was collected from 36 deployments during the first trial, and for cod (>33 cm), plaice and flounder from up to 24 deployments in the second trial.

A replicated, paired, controlled study in 2006 of two fished seabed sites in the southern North Sea off Belgium and England, UK (6) found that turning the diamond shaped mesh in the codends of beam trawls by 90° increased the size selectivity of two round-bodied fish species, but not of three flatfish species, compared to standard beam trawl codends. The lengths at which fish had a 50% chance of escaping were greater in turned diamond mesh codends for two round-bodied fish: whiting *Merlangius merlangus* (turned: 26 cm, standard: 12 cm) and pouting *Trisopterus luscus* (turned: 19 cm, standard: 11 cm); and for flatfish, they were similar for dab *Limanda limanda* (turned: 14 cm, standard: 14 cm) and plaice *Pleuronectes platessa* (turned: 13 cm, standard: 14 cm) and lower for sole *Solea solea* (turned: 19 cm, standard: 20 cm). By size class, all lengths of whiting and pouting larger than 10 cm had higher size selectivity in turned diamond mesh codends, while dab, plaice and sole larger than 16, 15 and 19 cm, respectively, had lower selectivity (data reported as selection curves). Trials were done by research vessel in January 2006 on fishing grounds along the Belgian coast and in the outer Thames Estuary off England. Data was collected from 15 deployments of two 4 m beam trawls towed side by side, each with a different codend: one with the netting orientation turned by 90°, and the other a traditional diamond mesh orientation (both 80 mm mesh size; see original paper for specifications). Covers attached over each codend collected escaped fish. Lengths of fish captured in the codends and covers were measured (sub-sampled when numbers were very high).

(1) Madsen N. & Valentinsson D. (2010) Use of selective devices in trawls to support recovery of the Kattegat cod stock: a review of experiments and experience. *ICES Journal of Marine Science*, 67, 2042–2050.

(2) Wienbeck H., Herrmann B., Moderhak W., Stepputtis D. (2011) Effect of netting direction and number of meshes around on size selection in the codend for Baltic cod (*Gadus morhua*). *Fisheries Research*, 109, 80–88.

(3) Herrmann B., Wienbeck H., Moderhak W., Stepputtis D. & Krag L.A. (2013) The influence of twine thickness, twine number and netting orientation on codend selectivity. *Fisheries Research*, 145, 22–36.

(4) Tokaç A., Herrmann B., Aydin C., Kaykac H., Unluler A & Gokce G. (2014) Predictive models and comparison of the selectivity of standard (T0) and turned mesh (T90) codends for three species in the Eastern Mediterranean. *Fisheries Research*, 150, 76–88.

(5) Herrmann B., Wienbeck H., Stepputtis D., Krag L.A., Feekings J & Moderhak W. (2015) Size selection in codends made of thin-twined Dyneema netting compared to standard codends: A case study with cod, plaice and flounder. *Fisheries Research*, 167, 82–91.

(6) Bayse S.M., Herrmann B., Lenoir H., Depestele J., Polet H, Vanderperren E. & Verschueren B. (2016) Could a T90 mesh codend improve selectivity in the Belgian beam trawl fishery? *Fisheries Research*, 174, 201–209.

2.52 Fit mesh escape panels/windows to a trawl net

- **Thirty-seven studies** examined the effects of fitting one or more mesh escape panels/windows to trawl nets on marine fish populations. Ten studies were in the North Sea[5,6,8,9,12,14,15,18,22,24] (UK, Netherlands, Norway), four studies were in each of the Baltic Sea[7,11,19,27] (Denmark, Sweden, Northern Europe), Kattegat and/or Skagerrak[10,21,23,26] (Norway/Sweden/Denmark) and the Northeast Atlantic Ocean[25],[29,36,37] (Iceland, UK, Northern Europe). Two studies were in the Gulf of Carpentaria[4,13] (Australia) and two were in the Bay of Biscay[31,32] (France). One study was in each of the Irish Sea[1] (UK), the Tasman Sea[2] (Australia), the Bering Sea[3] (USA), the Indian Ocean[16] (Mozambique), the Norwegian Sea[20] (Norway), the Pacific Ocean[30] (Chile), the Gulf of Maine[33] (USA) and the Tyrrhenian Sea[34] (Italy). Two studies were reviews[28,35] (Northern Europe), and one study was in a laboratory[17] (Japan).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled study in the Baltic Sea[11] found that there was no difference in survival between cod escaping from diamond mesh codends with or without square mesh escape windows.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated study in a laboratory[17] found that small immature masu salmon were able to actively swim (escape) through the meshes of square mesh panels under simulated trawl conditions.

OTHER (35 studies)

- **Reduce unwanted catch (29 studies):** One before-and-after study in the Baltic Sea[19] and 13 of 18 replicated studies (including one paired, four controlled, 10 paired and controlled, and one randomized, paired and controlled) in the North Sea[5,14,15], Kattegat and Skagerrak[26,21,23], Irish Sea[1], Tasman Sea[2], Bering Sea[3], Gulf of Carpentaria[4], Indian Ocean[16], Baltic Sea[7], Northeast Atlantic Ocean[25,36,37], Bay of Biscay[32], Tyrrhenian Sea[34] and the Pacific Ocean[30], found that square mesh escape panels/windows of varying designs and number fitted to diamond mesh trawl nets (bottom and pelagic), reduced the unwanted catches (non-target or non-marketable species/sizes) of all fish species monitored[1,2,3,4,7,14,19,25,26,37], all but one[5] and one of four[15] fish species and the total unwanted/discarded catch (fish and invertebrates combined)[2,16,36], compared to standard diamond mesh trawl nets, and the effect varied with panel/window design[4], position in the net[14] and/or fish body type[25], as well as catch size[3]. The other five studies[21,23,30,32,34] and a review study of mesh escape panel/window use in the Kattegat and Skagerrak[28], found that square mesh panels/windows did not reduce the unwanted catches of fish[21,23,30,34], Atlantic cod[28] and three of three commercial bottom fish species[32], compared to diamond mesh nets without panels/windows. Four of five replicated, controlled studies (including three paired) in the North Sea[8,12,24], Northeast Atlantic Ocean[29] and Gulf of Maine[33], found that large diamond mesh escape panels in diamond mesh trawl nets (beam and bottom) reduced unwanted catches of cod[8,24], whiting and haddock[29], and discarded catch (fish and invertebrates)[12], but not of whiting[8], compared to nets without large diamond mesh panels, and the effect varied with panel design[29] and vessel size[8]. The other study[33] found that the unwanted catches of only one of seven species/groups of non-target fish was reduced by a large diamond mesh panel. Two replicated, paired, controlled studies in the North Sea[18] and Baltic Sea[27] found that new or different configurations of square mesh panels/windows in diamond mesh trawl nets reduced unwanted fish[18] and cod[27] catches, compared to existing/standard panels or windows. One replicated, paired, controlled study in the Gulf of Carpentaria[13] found that diamond mesh trawl nets with either a top square mesh escape panel or a large supported opening (‘Bigeye’) reduced unwanted shark, but not ray and sawfish catches compared to standard trawl nets. One before-and-after study in the Bay of Biscay[31] found that supplementing a top square mesh escape window in a prawn trawl net with either a bottom window, a flexible escape grid or an increased mesh size diamond codend, did not reduce the unwanted hake catch.
- **Improved size selectivity of fishing gear (9 studies):** One review study of mesh escape panel/window use in the Kattegat and Skagerrak[28] and four of six replicated, controlled studies (including four paired) in the Baltic Sea[7], North Sea[6,22,9], northeast Atlantic Ocean[10,23], found that square mesh escape panels/windows in diamond mesh trawl nets improved the size selectivity of trawl nets for Atlantic cod[7,10,28] and haddock[6,10,22], compared to trawl nets without panels/windows, and there was no difference compared to standard trawl nets with reduced mesh circumferences[22], and the effect varied with panel position[6] and design[10]. The other two studies found no effect on the size selectivity of undersized fish[23], haddock, saithe or Atlantic cod[9], compared to standard trawl nets. One review study of gear size selectivity in the northeast Atlantic Ocean[35] found that the effect of fitting square mesh panels to trawl nets on haddock selectivity varied with panel mesh size, position, and time of year. One replicated, controlled study in the Norwegian Sea[20] found no difference in the size selectivity of cod and haddock between diamond mesh trawl nets fitted with either square mesh escape windows, rigid size-sorting escape grids or a large diamond mesh codend.

Background

Escape windows in trawl nets are sections or panels of netting with a mesh size and/or mesh shape (diamond or square) different to the rest of the codend or extension piece and are designed to provide an additional escape opportunity for fish. Factors that may affect the species and/or sizes of fish that are able to successfully escape through the meshes include: whether they are square- or diamond-shaped, mesh size, where they are placed in the trawl net (top or bottom, near or further away from the codend), the number of windows/panels and the behaviour of the fish. For example, top square mesh escape windows/panels have been used extensively in commercial prawn trawl fisheries to try and allow non-target fish to escape while retaining the target prawn/shrimp catch. Mesh escape windows/panels in trawl nets should thus reduce the amount of unwanted (non-target and/or non-marketable species) fish captured and allow the release of smaller individuals.

Evidence for a related intervention is summarized under *'Fishing gear modification - Modify the configuration of a mesh escape panel/window in a trawl net'.* Evidence of this intervention when used in combination with other interventions to reduce unwanted catch in trawl nets is summarized under '*Fishing gear modification - Fit mesh escape panels/windows to a trawl net and use square mesh instead of diamond mesh codend'* and *'Fit mesh escape panels/windows and a size-sorting grid (rigid or flexible) to a trawl net'*.

A replicated, paired, controlled study in 1990 of bottom fishing grounds in the Irish Sea, UK/Republic of Ireland (1) reported that diamond mesh prawn trawl codends fitted with a square mesh escape panel caught fewer unwanted and undersized whiting *Merlangius merlangus* than conventional trawls without an escape panel in a fishery for Norway lobster *Nephrops norvegicus*. Data were not statistically tested. Overall, trawl codends fitted with a square mesh escape panel retained 84% fewer undersized (<27 cm) whiting than conventional trawls. Trawl nets with a square mesh escape panel caught fewer undersized whiting for every tow (square mesh: 22–714 fish/tow, conventional: 52–2,952 fish/tow), and fewer undersized whiting for every kilogram of *Nephrops* in 17 of 19 tows (square mesh: 1–28 whiting/kg *Nephrops*, conventional: 1–70 whiting/kg *Nephrops*). The overall size composition of both whiting and *Nephrops* was similar for each trawl design. Data were collected in September and October 1990, from 19 valid paired trawl deployments, 3 to 11.5 h duration, performed under commercial fishing conditions. Two 70 mm diamond mesh trawls were fished simultaneously: one fitted with a square-mesh panel and one without. The square-mesh panel was 75 mm mesh size and 3 m long × 30 meshes in width and fitted to the upper trawl panel (see paper for specifications).

A replicated, paired, controlled study in 1995 of a seabed area in the Tasman Sea, Australia (2) found that fitting square mesh escape windows to the codend of a prawn trawl reduced the amount of overall unwanted catch (fish and invertebrates) and stout whiting *Sillago robusta* and long-spined flathead *Platycephalus longispinis*, compared to codends without square mesh windows, for two codend circumferences. The average weight of discarded catch (fish and invertebrates) was reduced by 35% (100 mesh) and 40% (200 mesh) in codends with square mesh windows (with: 20–40 kg, without: 32–70 kg). For two individual fish species caught in sufficient amounts, stout whiting and long-spined flathead, average numbers and weights of discards were reduced by 33–64% and 33–56% respectively. In addition, the average weight of the target king prawn *Penaeus* *plebejus* catch remained similar between trawl nets (with and without: 5–9 kg). Data were collected in March 1995 on a commercial trawler equipped with three trawl nets. The two outer nets were used to test four codends: a 40 mm diamond mesh codend, 100 or 200 mesh circumference, fitted with two square mesh windows, one inside the other of 40 mm (outer) and 50 mm (inner) mesh; and a control 40 mm diamond mesh codend, 100 or 200 mesh circumference and no square mesh windows (see paper for specifications). A total of 10 deployments for each of the four paired comparisons were done.

A replicated, randomized, paired, controlled study in 1994 of pelagic fishing sites in the Bering Sea off Alaska, USA (3) found that fitting square mesh escape panels to pelagic trawl nets reduced the amount of undersized walleye pollack *Theragra chalcogramma* in small but not large catches, compared to standard all-diamond mesh codends. The percentage catch of pollock smaller than 36 cm was lower in codends with square mesh panels than without, at catch sizes below 40 tonnes in weight (with: 6–15%, without: 20–46%) but was similar at catches of 40 tonnes and above (with: 19–25%, without: 18–25%). In July–August 1994, codends fitted with a top panel of square mesh of two different mesh sizes (95 mm and 108 mm) were compared with a standard codend diamond mesh codend of 85 mm (see paper for specifications). Commercial deployments of individual codends were done in a randomized block design, in daylight hours for a maximum duration of four h. Data were collected for each type of codend from seven to eight tows of catches below 40 tonnes and 3–10 tows above 40 tonnes. Codend catches were transferred from four catcher vessels to a factory trawler where sorting and sampling of pollack took place.

A replicated, paired, controlled study in 1995–1996 in an area of seabed in the Gulf of Carpentaria, Australia (4) found that prawn trawl nets fitted with a square mesh escape window reduced the catches of unwanted fish, and three variations of the window resulted in variable effects, compared to unmodified standard nets. Relative to standard nets, trawl nets fitted with a square mesh window alone caught 25–36% less unwanted fish catch. A square-mesh escape window and black canvas cylinder reduced unwanted fish catch by 33% in one trial, but catches were similar in another (16% less than standard). A square mesh window and 'hummer' grid reduced unwanted fish catch by 26% and a square mesh window made of glow-in-the-dark mesh caught similar amounts (17% less than standard). Catch weights of target prawns *Penaeidae* were only reduced in one of two tests of each of a square mesh window alone (35%) and in combination with a black cylinder (25%). Trials were done on a two-leg research vessel survey in February 1995. Data were collected from paired, 30 min deployments using a twin-trawl to tow different combinations of modified and standard nets in a semi-systematic block design. Catches from a standard prawn trawl net (45 mm codend mesh) fitted with a 150 mm square mesh panel (30 tows) or one of three panel variations (14–18 tows of each) were compared with unmodified standard net (35 tows) catches (see paper for specifications).

A replicated, paired, controlled study in 1993 of two seabed areas in the North Sea off Scotland, UK (5) found that prawn trawl nets fitted with a square mesh escape panel in the codend caught fewer undersized non-target haddock *Melanogrammus aeglefinus* and Atlantic cod *Gadus morhua*, but not whiting *Merlangius merlangus*, compared to a conventional trawl without a panel. Numbers of undersized haddock (<35 cm) and cod (<40 cm) were lower in codends with an escape panel than conventional codends (haddock, with: 3,207, without: 6,360; cod, with: 650, without: 976), and undersized whiting (<23 cm) catches were similar (with: 16, without: 37). Catches of marketable sizes were similar in panel and conventional codends for haddock (282 vs 284) and cod

(464 vs 485) but lower for whiting (1,671 vs 4,074). In addition, catches were similar in panel and conventional codends for undersized (<4 cm) Norway lobster *Nephrops norvegicus* (4,386 vs 4,940) but lower for legally sized lobster (4,103 vs 1,769). The selection length (the length at which half of fish of that size will escape and half will be retained) was higher in panel than conventional codends for haddock (28.1 vs 25.2 cm) and whiting (35.1 vs 31.4 cm) but similar for cod (29.8 vs 26.3 cm) and lobster (3.8 vs 3.8 cm). Two research cruises were carried out in Fladen Ground and East Ground in 1993 using a twin trawl. One trawl was fitted with a 2 × 1.15 m long square mesh (90 mm) panel 2 m ahead of the codend, and one used a conventional codend. Both codends used 90 mm diamond mesh. Two small mesh covers installed over the codends and square mesh panel collected the escaping catch. Sub-samples of cover and codend catches were sorted and weighed, and lengths recorded.

A replicated, paired, controlled study in 1998 on commercial fishing grounds in the North Sea, off Scotland, UK (6) found that fitting a square mesh escape panel to a bottom trawl net improved the size selectivity of haddock *Melanogrammus aeglefinus* in one of two panel positions, compared to a net without a panel. The estimated length at which haddock had a 50% chance of escape was greater with a square mesh panel positioned in the codend (25.7 cm) than without a panel (23.0 cm), and similar when positioned in the extension piece in front of the codend (22.8 cm). In addition, increasing the mesh size of the square mesh escape panel to 100 mm from 80 cm resulted in a selection length of 30.28 cm, but too few fish were retained to test statistically. In June 1998, trials were done 45 miles east of Aberdeen from a commercial fishing vessel using a twin-trawl. One of four test nets was fished on one side of the trawl and a small mesh (40 mm) codend net on the other side. Test nets were all 100 mm diamond mesh codends: two with an 80 mm square mesh panel positioned in either the codend or extension piece; one with a 100 mm square mesh panel; and one without a panel. Sixteen valid deployments were made. Codend catches were sorted separately and lengths of all the haddock measured.

A replicated, paired, controlled study in 1998 of a seabed area in the Baltic Sea, Denmark (7) found that trawl nets fitted with a square mesh escape window in the codend reduced catches of small unwanted cod *Gadus morhua* and improved size selectivity, compared to standard diamond mesh codends without a square mesh window. Average weights of cod escaped from codends with square mesh windows was higher than those without (with: 416–613 kg, without: 223–456 kg) and the selection lengths (the length at which half of fish of that size will escape and half will be retained) increased for all three window mesh sizes compared to standard codends of comparable mesh size without a panel (with: 41–53 cm, without: 28–46 cm) and increased with increasing mesh size. In June and July 1998, a total of 54 valid fishing deployments were done from a commercial trawler towing a twin trawl rig around the Danish island of Bornholm. Three modified standard codends, with 110, 125 and 135 mm square mesh escape windows, and three standard codends of 105, 120 and 140 mm diamond mesh size, were tested. The escape window was a single panel of square mesh, 3.5 m long and 1.4 m wide, inserted in the upper panel of the codend section. Covers were attached over each codend to collect escaping fish. Codend and cover catches were sorted and weighed by species. Sub-samples of cod were measured for length.

A replicated, paired, controlled study in 1994–1996 on bottom fishing grounds in the North Sea, the Netherlands (8) found that fitting a large diamond mesh escape panel to beam trawl nets resulted in the capture of fewer small Atlantic cod *Gadus morhua* in one of two cases, and similar amounts of small whiting *Merlangius merlangus* in two of two cases, compared to standard trawl nets without a large-mesh panel. On small fishing vessels, nets with a large-mesh panel caught fewer undersized (<35 cm) cod (with: 1,134 fish, without: 1,352 fish) and similar amounts of undersized (<23 cm) whiting (with: 577 fish, without: 673 fish) than standard nets. On large fishing vessels, there were no statistical differences in catches between net types for both undersized cod and whiting: (cod, with: 413 fish, without: 596 fish; whiting, with: 78 fish, without 109 fish). In addition, overall, commercial catches of cod, whiting, brill *Scophthalmus rhombus* and turbot *Scophthalmus maximus* were lower with the modified trawl compared to the standard trawl, and commercial catches of sole *Solea solea* and plaice *Pleuronectes platessa* were similar between trawl types (see original paper for data). Between November 1994 and June 1996, data were collected from 519 valid trawl deployments (sampling area was not reported) over 13 one-week trips on three fishing vessels targeting flatfish; one small (300 hp engine), and two large (1,500 & 2,000 hp engines). On each vessel, a standard diamond mesh trawl net modified with a large diamond mesh top panel, and a standard diamond mesh trawl net were towed simultaneously (see paper for gear specifications). All cod and whiting caught were measured and marketable sizes of other fish.

A replicated, paired, controlled study in 2001 in two areas of seabed in the North Sea off Norway (9) found that trawl nets fitted with a square mesh escape panel in the codend did not improve the size selectivity of undersized haddock *Melanogrammus aeglefinus,* saithe *Pollachius virens* or Atlantic cod *Gadus morhua*, compared to a conventional diamond mesh codend without a square mesh panel. The estimated length at which a fish has a 50% chance of escape was not statistically different between codend types for three of three species: haddock (with: 34.4 cm, without: 35.5 cm), saithe (with: 50.5 cm, without: 46.4 cm) and Atlantic cod (with: 44.5 cm, without: 40.9 cm). In addition, this value increased with increasing catch size in both codend types for haddock but was similar at all catch sizes for saithe and cod (data reported as statistical models). Fishing trials were carried out in October 2001 in The Patch and Alle Bank fishing grounds off Bergen. Seven deployments were done with each codend type: one trawl net a standard 120 mm diamond mesh codend fitted with a 3 m long square mesh panel (110 mm mesh) and one a 120 mm diamond mesh codend (see paper for specifications). Size-selection of each codend was calculated by comparing codend catches to catch in a small mesh (50 mm mesh) codend towed simultaneously.

A replicated, paired, controlled study in 2000 of a bottom fishing ground in the Skagerrak, northern Europe (10) found that fitting square mesh escape windows to bottom trawl codends improved the size selectivity of small Atlantic cod *Gadus morhua* in two of two cases and of haddock *Melanogrammus aeglefinus* in one of two cases, compared to a standard codend without escape windows. For cod, the selection length (the length at which fish have a 50% chance of escape) was greater in both top- and side-window codends than no windows (top: 29.9 cm, side: 29.9 cm, none: 25.5 cm) and for haddock, the selection length was higher only in the top-window codend (top: 31.9 cm, side: 28.8 cm, none: 28.8 cm). Trials were done in June 2000 on a commercial fishing vessel towing a twin-trawl net. Data were collected from 37 deployments of a small-meshed (35 mm) control codend fished at one side and a test codend at the other side, and sides changed regularly. Three codend types were tested: a standard codend (104 mm mesh) with an 85 mm square mesh top window; a standard codend with two 85 mm square mesh side windows; and a standard codend (see paper for specifications).

Deployments were 2.9 h duration, speed 3.1 knots and 20–80 m depths. Fish sampling procedure was not reported.

A replicated, controlled study in 1997–1998 in a coastal bay in the Baltic Sea, off Sweden (11) found that survival of cod *Gadus morhua* escaped from trawl nets fitted with square mesh escape panels (two types) was similar to cod escapee survival from a standard diamond mesh trawl. Survival of cod escaped from codends with square mesh escape panels was not statistically different from a standard codend (two side square panels: 25–100%, one large top panel: 96–100%, standard: 42–100%). In addition, the survival of all escapees decreased with unusually high seawater temperatures in the bay (normal <10°: 92–100%; high >15°C: 25–100%). Data were collected in Hanö Bay from 30 trawl deployments of 3 h at 30–55 m depths on a commercial bottom trawl vessel in August 1997–April 1998. Three codend types were tested: a Danish type 105 mm side escape window codend (14 tows); a 105 mm square mesh top-panel codend (Bacoma window) (four tows) and a standard 120 mm diamond mesh codend (12 tows). Escapee cod were collected in cages attached to the end of the trawl during the last 20 minutes of each tow, kept on the seabed for 5–14 days, after which survival was recorded.

A replicated, controlled study in 1999 on a bottom fishing ground in the North Sea, the Netherlands (12) found that fitting large diamond mesh escape panels (drop-out panel) to beam trawl nets, typically reduced the amount of discarded catch (fish and invertebrates), compared to a standard diamond mesh trawl. Overall, discarded catch was reduced by 3–26% in nets with large mesh panels, irrespective of panel configuration. Nets with panels of 19 large meshes caught less discarded catch in three of four configurations (19 panel: 75–97 kg/h, standard: 86–128 kg/h) and similar amounts in one (19 panel: 33 kg/h, standard: 34 kg/h), and a 500 mm mesh size performed better than 720 mm. Discarded catch was reduced in a 12-mesh, 500 mm panel (12 panel: 110 kg/h, standard: 123 kg/h) and was similar in a 16-mesh, 500 mm panel: (16 panel: 102 kg/h, standard: 136 kg/h). Catches of retained fish of target species, although lower in most configurations, were not significantly reduced in nets with panels (panel: 15–44 kg/h: standard: 14–48 kg/h). Six parallel strips of seabed, 2,000 m x 30 m, were sampled by two research vessels in January and March 1999 on the Oyster Ground. Data were collected from a total of 68 deployments using either an 8- or 12-m beam trawl and one of six configurations of large diamond mesh panel (3 mesh numbers, 2 mesh sizes, with or without a sheet – see paper for specifications), towed simultaneously with a standard diamond mesh trawl net without a panel. Target fish catch and discarded catch of fish and invertebrates combined were weighed.

A replicated, paired, controlled study in 2001 of bottom fishing grounds in the Gulf of Carpentaria, Australia (13) found that prawn trawl nets fitted with either a top square mesh escape panel or a large, supported opening ('Bigeye'), reduced unwanted catch of sharks *Selachii*, but not rays *Batoidea* and sawfish *Pristidae*, compared to conventional diamond mesh trawl nets. Shark catches were reduced by 17% in trawl nets fitted with one of two types of fish escape opening (results combined for nets with either a square mesh panel or a Bigeye opening) and catches of rays and sawfish were similar. In addition, total target prawn catch was similar in nets with a square mesh panel and reduced by 4% with the Bigeye escape opening. Data were collected from up to 1,612 paired trawl comparisons (3,224 nets sampled over 442 nights of trawling) from 23 different vessels in August-November 2001, in which a wide range of catch reduction devices were tested. Standard prawn trawl nets fitted with either a square mesh panel or a Bigeye large escape opening and standard nets without an escape panel/opening were towed simultaneously from one randomly assigned side of each vessel (see paper for specifications). All codend catches were sorted and identified by species, weighed and counted.

A replicated, paired, controlled study in 2001 on bottom fishing grounds in the North Sea off Scotland, UK (14) found that square mesh escape panels fitted to bottom trawl nets reduced the unwanted catch of small haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus*, compared to standard trawl nets, and the effect varied with position of the panel in the net. For all three panel positions, average relative catch rates of haddock and whiting smaller than 30 cm were lower in nets with square mesh escape panels than nets with no panels (data presented as average catch ratios by length). Whiting catches in nets with panels positioned 6–9 m and 9–12 m from the codend were similar and lower than panels positioned 3–6 m away and no statistical differences were found for haddock between panel positions. In addition, the selection length of haddock (the length at which half of fish of that size will escape and half will be retained) of panel nets was higher than no panel nets across all configurations (3–6 panel: 27.9 cm, 6–9 panel: 30.4 cm, 9–12 cm: 29.9 cm; no panel: 16.6 cm). Data were collected from a total of 30 trawl deployments of one of four test nets (panel or no panel) fished simultaneously with a small mesh (40 mm) control codend. Four 100 mm diamond mesh codends were tested: three with 90 mm square mesh panels inserted in either the codend or extension at 3–6, 6–9 and 9–12 m from the codend, and one with no panel (see paper for specifications). Tows were carried out on commercial fishing grounds 65 miles north-east of Fraserburgh in March 2001. Tows were 90–150 minutes at 2.4–3.3 knots. Seven or eight tows were completed with each test net. Codend catches of the target species, haddock and whiting, were sorted, weighed and the lengths of a subsample measured.

A replicated, paired, controlled study in 1999–2000 of a seabed area in the North Sea off Shetland, UK (15) found that fitting a square mesh escape panel to a bottom trawl net reduced the catch of unwanted, small whiting *Merlangius merlangus*, but not Atlantic cod *Gadus morhua,* haddock *Melanogrammus aeglefinus* or monkfish *Lophius piscatorius*, compared to a net with no panel. The average catch rates of whiting below minimum landing size (27 cm) were reduced by 34% with a panel (with: 6.4 fish/h, without: 9.4 fish/h) and catches of undersized cod ≤35 cm (with: 3.4 fish/h, without: 3.2 fish/hr), haddock ≤30 cm (with: 80.0 fish/h, without: 77.0 fish/hr) and monkfish ≤34 (with: 3.2 fish/h, without: 3.0 fish/hr) were similar. In addition, catches of some commercial sizes of whiting and cod were reduced by 10–41%. Data were collected from a total of 172 deployments of a 100 mm diamond mesh codend fitted with a 90 mm mesh square mesh panel, 6–9 m from the codend and an identical cod-end with no panel, attached to the same net (see paper for specifications). Codends were alternated every 24 h and tows were 2.5–6.0 h. Codend catches were sorted and all haddock, whiting, cod and monkfish were counted, and total length measured.

A replicated, paired, controlled study in 2005 of an area of seabed in the Indian Ocean, off Mozambique (16) found that fitting a prawn trawl net with a square mesh escape panel, with or without a rigid size-sorting escape grid, reduced the amount of overall discarded catch (fish and invertebrates), compared to a conventional trawl without square mesh panels. Average catch rates of discards (90% fish, 10% invertebrates) were lower in nets with square mesh panels, either alone or in combination with a grid (panel: 37.4 kg/h, panel+grid: 29.7 kg/h; no panel: 50.4–56.4 kg/h). In addition, panel nets did not reduce catches of retained fish (panel: 4.0 kg/h, panel+grid: 3.6 kg/h; no panel: 4.9 kg/h), but target prawn catch (mainly *Fenneropenaeus indicus*) was reduced in panel and grid nets only (panel: 12.8 kg/h, panel+grid: 5.61 kg/h; no panel: 7.52–12.4 kg/h). Trials took place on the Sofala Bank trawl grounds off the Zambezi River in February 2005 by a twin-rigged trawler towing test trawl nets with escape panels alongside a conventional trawl in depths of 6–21 m. A Data were collected from 11 tows with a 143 mm square mesh escape panel inserted on the top of the net near the junction of the extension piece and codend, and eight tows of the square mesh panel combined with an aluminium size-sorting grid (Nordmøre), 100 mm bar spacing (see paper for specifications). Codend catches were sorted into commercial/non-commercial portions, counted and weighed.

A replicated study (yet not stated) in a laboratory in Japan (17) found that small masu salmon *Oncorhynchus masou* were able to actively escape through square mesh escape panels fitted to a finfish trawl under simulated trawling conditions, regardless of panel orientation, and escape ability was not typically affected by towing speed, but was affected by the light conditions. Across all panel orientations, more salmon escaped in light conditions than dark, irrespective of towing speed (light: 20–100%, dark: 0–40%), with none able to escape at all in the dark through either a flat-fitted panel or a backward-sloping panel at the higher speed, and only 13–40% through forward-sloping panels. In light conditions, 100% of salmon escaped through a forward-sloping panel at both towing speeds. Increasing the towing speed to 1.5 from 1 knot increased the escape rate through a backward-sloping panel from 33 to 67% but reduced it from 40 to 20% in the flat-fitted panel. Six trials were done to test three panel orientations and two towing speeds (1 and 1.5 knots); three in dark and three in light conditions. For each trial, five small salmon (12–14 cm length) were released into a circular flow tank and forced to swim for a maximum of 30 min inside a framed net. The square mesh panel (60 mm mesh size) was fixed to the bottom net frame at three orientations: flat, forward- or backward-facing, and escapees monitored by video camera. The year the study took place is not reported.

A replicated, paired, controlled study in 2005–2006 of bottom fishing grounds in North Sea, UK (18) found that trawl nets fitted with two novel square mesh escape panel designs allowed more unwanted and undersized fish to escape capture, compared to industry standard square mesh panels. Trawl net codends fitted with an additional secondary escape panel in front of the industry standard panel allowed more undersized whiting *Merlangius merlangus* (<27 cm, 52%), Atlantic cod *Gadus morhua* (<35 cm, 45%), plaice *Pleuronectes platessa* (<25 cm, 47%) and haddock *Melanogrammus aeglefinus* (<30 cm, 66%) to escape capture compared to trawls with the industry standard panel alone. Trawls fitted with a modified panel of white 2.5 mm twine (95 mm mesh) in place of the standard green 4.0 mm (87 mm mesh) panel allowed more undersized whiting (45%), cod (35%) and haddock (58%) to escape capture and catches of plaice were similar. Total catch of unwanted and discarded target Norway lobster *Nephrops norvegicus* was lower using both modified escape panel designs than the industry standard. Data were collected in November 2005–January 2006 from 20 comparative trawl net deployments by a twin-rig trawler on commercial fishing grounds in the Farn Deeps. Two variants of square mesh panel codend, one with a second panel fitted in front of the industry standard panel, and one with a replacement panel of different mesh size and colour, were towed simultaneously with a standard trawl codend fitted with the industry standard escape panel (see paper for gear specifications). The catches of the main commercial fish species caught were analysed.

A before-and-after study in 2003–2005 in a heavily fished area of seabed in the Baltic Sea, Northern Europe (19) reported that after a change in trawl net type was implemented, to a square mesh escape window codend from a standard diamond mesh codend, there was a short-term reduction in discarded undersized Atlantic cod *Gadus* *morhua* in the Baltic trawl fishery. Data were not statistically tested. Average cod discard rate (in numbers) was reduced to 0.11 in 2004, after the escape window codend was used, from 0.23 in mid-2003. In 2005, the discard rate increased to 0.31, despite the net control measure still being in place. In January 2003, the minimum landing size of cod was increased from 35 to 38 cm and resulted in large numbers of cod discarded because undersized fish were being caught. From September 2003, vessels participating in the Baltic cod trawl fishery were required to use nets fitted with a square-mesh escape window in the upper rear panel of the codend (a Bacoma window) with a minimum window mesh size of 110 mm. This replaced the 130 mm diamond mesh codend most vessels were using. Discard data was collected from the Swedish cod fishing fleet by on-board observers.

A replicated, controlled study in 2005–2006 of two seabed areas in the Norwegian Sea, northern Norway (20) found that fish trawl nets fitted with square mesh escape windows did not improve the size-selection of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinnus*, compared to trawl nets fitted with rigid size-sorting escape grids or a large diamond-mesh codend. For cod, the average length at which fish had a 50% chance of escape (selection length) was similar in nets with escape windows (53.9 cm) to nets with a grid (56.1 cm) and lower than a large diamond mesh codend (60.7 cm). For haddock, average selection length was similar between all three codends: (escape windows: 50.6 cm, grid: 50.2 cm, large diamond: 49.9 cm). In addition, all selection lengths were higher than the minimum landing sizes of 47 cm (cod) and 44 cm (haddock). Data were collected from 62 deployments, off Finmark and Troms in December 2005–March 2006, of a trawl net with two codends: one an experimental codend and one a control diamond-mesh codend with a small-mesh inner net. Experimental nets were a 135 mm diamond-mesh codend fitted with two lateral escape windows; a 135 mm diamond-mesh codend fitted with a 55 mm sorting grid (Sort-V); and a codend of 155 mm diamond mesh.

A replicated, paired, controlled study in 2003 of an area of seabed in the Kattegat and Skagerrak, northern Europe (21) found that fitting a square mesh escape panel to the codend of a prawn trawl did not typically reduce the catches of undersized and discarded fish, compared to a trawl net without an escape panel. Total catch numbers of undersized fish were lower for two of eight species (see paper for list of species) in panel nets (with: 46–748, without: 86–1,017), similar for five species (with: 20–321, without: 20–307; for three species, total numbers across all sizes reported only) and higher for one (with: 41, without: 22). In addition, catch number of target *Nephrops norvegicus* below minimum landing size was reduced in panel nets (with: 10,479, without: 11,966) and was similar above (with: 6,771, without: 6,916). Data was collected in August and September 2003, from 24 trawl deployments by a single vessel towing two trawl nets side by side. One side was a 78 mm diamond mesh codend fitted with a 93 mm square mesh panel (93 mm) in the top panel of the extension section; the other side was a 78 mm diamond mesh codend with no escape panel. Side of vessel each net was towed was swapped every sixth tow. Tow duration averaged 7 h at 2.5 knots. Codend catches were sorted into commercial and non-commercial portions, counted and weighed.

A replicated, controlled study in 2002 of a seabed area in the North Sea, Norway (22) found that a fish trawl codend fitted with a square mesh escape panel improved the size-selection of haddock *Melanogrammus aeglefinus*, compared to a standard trawl codend without an escape panel, and had similar size-selectivity as standard trawl codends with reduced circumferences. The length at which fish had a 50% chance of escape (selection length) was higher in a codend with an escape panel (41.8–46.6 cm) than without in a standard 100 mesh circumference codend (27.0–39.7 cm) and similar to two codends with decreased mesh circumferences (60 meshes: 37.1–44.7 cm, 80 meshes: 32.6–44.7 cm). Data were collected from 23 trawl deployments on fishing grounds west and south west of Bergen in August–September 2002 using a twin-rig trawler. Four codend types were tested: a 120 mm diamond mesh codend fitted with a Bacoma-type 110 mm square mesh panel; and three 120 mm diamond mesh cod-ends of 100 (standard), 80 and 60 open meshes in circumference (see paper for specifications). Test codends were towed alongside a small mesh (50 mm) codend.

A replicated, controlled study in 2005 of a seabed area in the Skagerrak and Kattegat, northern Europe (23) found that fitting a square mesh escape panel to a prawn trawl net did not typically reduce the catches of undersized fish or improve the size-selection, compared to a standard diamond mesh codend without a panel. Overall, the total catches of six of seven fish species (see paper for species tested) below their respective minimum landing sizes were lower in the net with a square mesh panel (with: 68–433 fish, without: 77–747 fish) but a significant reduction was reported only for haddock *Melanogrammus aeglefinus*. The length at which fish had a 50% chance of escape was higher in nets with a square mesh panel for haddock *Melanogrammus aeglefinus* (with: 43.8 cm, without: 22.9 cm), similar for five fish species (with: 18.2–34.5 cm, without: 22.3–26.1 cm) and lower for plaice *Pleuronectes platessa* (with: 18.8 cm, without: 21.9 cm). There was no difference in selection length for catches of the target prawn *Nephrops norvegicus* between nets (with: 23.6 mm, without: 27.1 mm). In September and October 2005, trials were done by commercial fishing vessel using a twin-trawl net. Paired hauls were carried out with a control small mesh (40 mm) codend paired with either: a standard 90 mm diamond-mesh codend modified with a 120 mm square mesh panel or a standard 90 mm unmodified codend. For each comparison, 18 hauls were completed. All catches were sorted by species and weighed. Total lengths were measured for commercially important fish species and carapace length for *Nephrops*.

A replicated, paired, controlled study in 2008 of a seabed area in the North Sea, off Scotland, UK (24) found that fitting escape panels of large diamond mesh in the forward sections of a bottom trawl net reduced catches of unwanted Atlantic cod *Gadus morhua*, compared to trawl nets with sections of standard mesh size. Fewer cod were caught in the trawl net with escape panels than without (with: 3–511 kg/tow, standard mesh: 7–1,019 kg/tow), was dependent on length (45% fewer cod at 35 cm and 19% fewer cod at 80 cm), and the reduction significant for cod up to 78 cm in length. In addition, catches of smaller monkfish *Lophius piscatorius* and megrim *Lepidorhombus whiffiagonis* were reduced, by 37% at 37 cm and 43% at all lengths, respectively (with: 0–261 kg, without: 0–319 kg), and were similar for haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus* (with: 20–927 kg, without: 17–804 kg). Data were collected in October-November 2008 from 30 paired trawl deployments on a commercial twin rig trawler on bottom fishing grounds 65 miles west of Shetland. The vessel towed identical nets apart from the test net having two panels in the top section and one in the bottom and wings made from 300 mm diamond mesh netting instead of the standard 160 mm diamond mesh ('Orkney Gear' - see paper for specifications). Catches from each net were sorted by species and weighed. Lengths of selected species were measured.

A replicated, controlled study in 2009 in two areas of seabed in the North Atlantic Ocean off Scotland, UK (25) found that prawn trawl nets fitted with a square mesh escape panel typically reduced the catches of unwanted small commercially targeted roundfish compared to a small-mesh control trawl net without a panel, and for flatfish, the effect depended on panel position in the net. Data were reported as relative catch ratios and statistical test results. For both panel positions (6–9 and 12–15 m away from the codend), overall catch rates of smaller sizes of hake *Merluccius merluccius,* Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus*, and whiting *Merlangius merlangus* were lower than the control net. Fewer small plaice *Pleuronectes platessa* were caught in the 6–9 m panel but more were caught in the 12–15 m panel net relative to the control. For witch *Glyptocephalus cynoglossus*, more were caught in the 6–9 m panel and similar numbers were retained in the 12–15 m panel net. Overall catch rates of target Norway lobster *Nephrops norvegicus* under 37 mm were reduced in both panel nets and rates of larger, legally sized Norway lobster (≥39 mm) were similar. In 2009, paired trawl deployments were carried out in the South Minch (July) and Fladen Grounds (March) around Scotland. Thirty-two twin-trawls were undertaken, simultaneously towing a test trawl net fitted with a 120 mm square mesh panel, 3.1 × 1.0 m and 80 mm diamond mesh codend, and a conventional trawl net with a small (40 mm) mesh codend. Fifteen trawl deployments were done with the panel positioned 6–9 m ahead of the codend and 17 with it positioned 12–15 m ahead of the codline. Trawl nets were deployed for 3–3.5 hours in 108–139 m depths and all catch counted and measured.

A replicated, paired study in 2007 in two areas of seabed in the Skagerrak and Kattegat, northern Europe (26) reported that prawn trawl nets fitted with a square mesh escape panel allowed high proportions of undersized Atlantic cod *Gadus morhua* and plaice *Pleuronectes platessa* to escape capture, and high proportions of marketable sizes of non-target commercial fish. Data were not tested for statistical significance. For two of two panel positions, 93% of cod below the minimum landing size (30cm) and 86–87% above it escaped (92–93% overall) and between 75–82% of undersized (<27 cm) plaice (77–84% overall). Seven other non-target commercial fish species were caught, of which generally large proportions of legally sized fish escaped: saithe *Pollachius virens* (95–97%); lemon sole *Microstomus kitt* (55–75%); haddock *Melanogrammus aeglefinus* (80–86%); witch *Glyptocephalus cynoglossus* (50–60%); dab *Limanda limanda* (70–100%); pollock *Pollachius pollachius* (82–100 %); and hake *Merluccius merluccius* (90–93 %). In addition, 33–37% of legally sized individuals of the target Norway lobster *Nephrops norvegicus* escaped capture. Nine paired trawl deployments of two nets fitted with a square mesh escape panel (300 mm mesh), one 2.7 m and one 1.35 m in front of the codend, were carried out in June 2007. Codends were 90 mm diamond mesh. Full trawl designs are provided in the original study.

A replicated, paired, controlled study in 2000 of a pelagic area in the Baltic Sea, Denmark (27) reported that three of three configurations of pelagic trawl codends, including two with square mesh escape windows, allowed large proportions of Atlantic cod *Gadus morhua* to escape, and reduced the catches of undersized cod compared to an existing type of square mesh window codend. Data were not tested for statistical significance. High numbers of cod escaped from each of the tested codends relative to the numbers retained; codend with bottom escape windows (escaped: 17,026–18,765, retained 1,998–5,466); large diamond mesh codend (escaped: 13,202–16,089, retained: 2,317–3,228); and top window codend (escaped: 6,906–27,616, retained: 6,906–27,616). Compared to the square mesh codend in use by the fishery (Bacoma), catches of undersized (<38 cm) cod in the three test codends were reported to be reduced to 0.1–1.4% from 5.4%. Trials were conducted by two commercial vessels around the Bornholm Deep in the main pelagic cod fishery season, April–June 2000. Data was collected from

10–11 deployments of each of three codend types on one vessel and 6–7 on the other (total 51). Tow duration was 8–11 h at 2.5 knots and 90–95 m depth. The three codends tested were: a codend with two 125 mm bottom square mesh escape windows; a codend with one 125 mm top escape window; and a standard diamond mesh codend of 135 mm mesh (see paper for gear specifications). Covers installed over the codends sampled escaping fish catch. Lengths of all fish in the covers and codends were measured. Data for the 110 mm Bacoma codend were taken from a previous study (7).

A review in 2005–2010 of ten trawl gear studies in bottom fishing grounds in the Kattegat and the Skagerrak, Northern Europe (28) reported that the effectiveness of selective devices in prawn trawl nets in reducing the amount of unwanted small Atlantic cod *Gadus morhua* varied with the device used, and that square mesh escape windows had limited or no significant effect on unwanted cod catches but did improve the overall size selectivity of nets compared to conventional diamond mesh codends. Square mesh escape windows reduced the number of undersized (<40 cm) cod caught in one of three studies (by 59%) and no effect was reported for the other two. Increasing the mesh size in the window was reported to have no significant effect (one study) but the location of the window did (two studies). Overall, trawl nets with square mesh escape panels/windows had higher selection lengths (the length at which the fish have a 50% chance of escape/capture) than diamond mesh codends without (with: 27–30 cm, without: 15–26 cm – not statistically tested). The review summarized the effects of different codend selective devices on catches of cod from studies of trawl nets used to target Norway lobster *Nephrops norvegicus* in the Kattegat and Skagerrak. The selective devices were mesh escape windows, increased codend mesh size, square mesh codends, turned mesh codends and a sorting box (see paper for specifications and data).

A replicated, paired, controlled study in 2009 of bottom fishing grounds in the northeast Atlantic Ocean off Iceland (29) found that one of two designs of a diamond mesh escape panel fitted to prawn trawl nets, reduced the catches of unwanted and undersized whiting *Merlangius merlangus* and haddock *Melanogrammus aeglefinus*, compared to standard trawl nets with two square mesh escape panels. Overall, diamond mesh escape panels reduced the total catches of whiting and haddock by 43–48% and 34–57% respectively compared to the square mesh panel trawls. However, only the shorter design of large mesh panel reduced the catches of smaller individuals, and there were no size related differences for haddock and cod in the longer panel design (data reported as statistical models). In addition, target Norway lobster *Nephrops norvegicus* catches were reduced by 16–42% and fewer smaller (<50 mm) *Nephrops* were caught in the shorter panel trawl. In June 2009, data were collected from 22 deployments of two test nets and a standard *Nephrops* trawl nets towed in pairs on a commercial twin-rig vessel. In modified nets, the 135 mm diamond mesh top panel was narrower and longer than the bottom panel resulting in forced opening of the meshes. One design had a 23.2 m long upper panel (five tows) and the other a 16.1 m long upper panel (17 tows). Standard trawl nets were identical except for two mandatory 200 mm square mesh upper panels in place of the test diamond mesh panels. Full trawl details are given in the original study.

A replicated, controlled study in 2008–2009 of bottom fishing grounds in the Pacific Ocean off Chile (30) found that crustacean trawl nets fitted with square mesh escape panels did not allow more unwanted fish to escape capture than nets without, however, nets with a panel and increased codend mesh size did. In the first of two trials, the average escape rates of Chilean hake *Merluccius gayi gayi* and bigeye flounder *Hippoglossina macrops* were similar in 56 mm mesh codends with and without a panel, and higher in 70 mm codends with a panel (56 mm/panel: 3–8%, 70 mm/panel: 14–23%, 56 mm/no panel: 1%). In the second trial, the average escape rates of four of four fish species/groups (Aconcagua grenadier *Coelorinchus Aconcagua*, cardinalfish *Apogonidae*, Chilean hake and cusk-eel *Ophidiidae*) were similar in 56 mm codends with and without a square mesh escape panel (panel: 1–88%, no panel: 0–94%). Fish data were collected from two trials in December 2008 (37 tows) and June-July 2009 (40 tows). Three codend types were tested: a 56 mm diamond mesh codend with an 80 mm mesh square mesh top escape panel (both trials), a 70 mm diamond mesh codend with an 80 mm mesh square mesh top escape panel (trial one), and a 56 mm diamond mesh codend without a panel (both trials). In both trials, the codends tested were changed after two or three tows, and the order used was randomized. Covers over the escape panels and sampled the escaping catch. Fish caught in large enough quantities were analysed.

A before-and-after study in 2003–2012 of bottom fishing grounds in the Bay of Biscay off France (31) found that following the introduction of prawn trawl nets fitted with top square mesh escape panels and in combination with one additional modification (either a bottom square mesh escape panel, a flexible escape grid, or an increased codend mesh size), did not typically affect the amount of unwanted hake *Merluccius merluccius* caught. None of the trawl modifications, individually or in combination, affected the weight, number or length of hake caught (data reported as statistical model results). The percentage of hake discarded was 61–78% in the period before trawl regulations were introduced (2003–2005), and 31–72% in the period after its introduction (2006–2012). Total hake discard weight was 1.2–2.7 thousand tonnes before and 0.5–2.8 thousand tonnes after the regulations. Standardised length of hake caught before and after the regulations was 8–9 cm and 7–11 cm respectively. In addition, effects on target catches were variable but modifications typically reduced catches of undersized Norway lobster *Nephrops norvegicus*. From 2005, all *Nephrops* trawls nets were required to fit a 100 mm square mesh panel in the upper codend to allow escape of hake. In 2008 vessels catching >50 kg of *Nephrops* a day were required to include at least one additional measure to reduce undersized *Nephrops* catches: a 60 mm square mesh lower panel; a 13 mm flexible grid in the codend; or an 80 mm codend (increased from 70 mm). Data from on-board fisheries observers were analysed for the period 2003–2012, before and after the regulations were implemented.

A replicated, controlled study in 2011 of bottom fishing grounds in the southern Bay of Biscay, France (32) reported that bottom trawl nets fitted with square mesh escape panels did not increase the overall escape of undersized catch of three of three fish species, relative to those escaping from the codend. Data were not statistically tested. For fish under the minimum legal size that entered the net, the square mesh panel allowed 0.7% of hake *Merluccius merluccius*, 11.9% of poor cod *Trisopterus minutus* and 0.9% of striped red mullet *Mullus surmuletus* to escape, while 47.3% of undersized hake, 71.4% of undersized poor cod and 53.9% of undersized red mullet escaped through the meshes of the codend. Data was collected from 15 trawl deployments on a research survey in November-December 2011. A trawl codend of 70 mm diamond mesh fitted with one 100 mm square mesh panel located 13 m from the codend was tested (see paper for specifications). Covers installed over the panel and codend collected escaping fish. Fish in both the cover and codend were identified, counted and lengths measured.

A replicated, controlled study in 2011–2012 of a seabed area in the Gulf of Maine, USA (33) found that fitting a large diamond-mesh escape window to a groundfish trawl net reduced the unwanted catch of one of seven non-target fish species/groups compared to a conventional small-mesh trawl. Catch rate of one of seven non-target fish species/groups (see original paper for species individual data) was reduced by 24% using the escape window (with: 1.4 kg/ha, without: 1.8 kg/ha) but was similar for six (with: 0.3–1.3 kg/ha, without: 0.3–1.4 kg/ha). The catch rate of the target species, silver hake *Merluccius bilinearis*, was similar with and without the window (with: 33 kg/ha, without: 38 kg/ha). In November 2011 to January 2012, a total of 58 alternating trawl deployments were made of a conventional silver hake trawl net fished either with a large diamond mesh escape window or as an unmodified conventional trawl net. Trawl designs were alternated via the addition or removal of a small-mesh panel zipped over the large mesh window. The escape window was 5 × 7 m large diamond mesh (330 mm) inserted in the lower panel of the trawl near the codend. The trawl net was small-mesh (50 mm) and equipped with a mandatory Nordmøre-type escape grid of 50 mm bar spacings. All catch was sorted and weighed for each tow.

A replicated study (year not stated) of a seabed area in the Tyrrhenian Sea, Italy (34) reported that fitting a square mesh escape panel to a bottom trawl net allowed only a small proportion of the undersized and non-target fish to escape capture. Data were not tested for statistical significance. For four of four fish species (target: Atlantic horse mackerel *Trachurus trachurus*, European hake *Merluccius merluccius*, red mullet *Mullus barbatus*; non-target: poor cod *Trisopterus minutus capelanus)* total percentage escape of fish through the square mesh was 0.8–5.3%. For fish below the minimum landing size, a total of 8.6% horse mackerel, 0.9% hake and 7.7% of red mullet escaped through the panel, representing 9.1, 1.3 and 25.0% for mackerel, hake and red mullet respectively, of the total escape of undersized individuals (panel and codend combined). Losses of marketable sizes through the panel were 0.5% for horse mackerel, 0% for hake and 0.9% for red mullet. A standard commercial Italian trawl net was fitted with a 50 mm square-mesh panel in the top of the final tapered section trawl body, 8 m in front of the codend. The codend was 6 m long and 50 mm diamond mesh. Eight trawl deployments were carried out (sampling times/year unspecified). Small-mesh (20 mm) covers installed over the square mesh panel and codend collected the escaping individuals. Both the cover and codend catches were weighed and sorted and the length of the three target fish species measured to the nearest 0.5 cm.

A review in 2016 of bottom trawl size selection data from fishing trials in the northeast Atlantic Ocean (35) found that the effect of fitting a square mesh panel in a diamond mesh trawl on improving size selectivity of the gear for haddock *Melanogrammus aeglefinus* depended on panel mesh size and position, and time of year, and in diamond mesh trawl nets without square mesh panels haddock selectivity increased with larger mesh size codends, smaller codend circumference and thinner twine thickness. The length at which 50% of haddock are likely to escape from the gear increased by 3.8 cm for each 10 mm increase in panel mesh size, but the effect of square mesh panels on the overall (panel plus codend) size selectivity of the gear for haddock varied with panel mesh size, position (greater closer to the codend), and time of year (data reported as statistical results). The length at which 50% of haddock are likely to escape from the gear increased by 3.4 cm for every 10 mm increase in codend mesh size, 1.3 cm for every decrease in codend circumference by 10 meshes and by 1.4 cm for every 1 mm decrease in twine thickness. This study presents a meta-analysis of haddock size-selection data collected on 24 vessels between 1991–2009, by Marine Scotland Science (formerly Fisheries Research Services). The final dataset was based on 614 fishing deployments from 18 trials (one excluded) of the combined size selection of a diamond mesh codend and a square mesh escape panel in the upper part of the codend or extension, and 20 trials (one excluded) of diamond mesh codend selection.

A replicated, controlled study in 2014–2015 of fishing grounds in the North Sea, Skagerrak and Baltic Sea, northern Europe (36) found that unrestricted commercial trials of a range of trawl net modifications, including the fitting of mesh escape panels, reduced the proportion of discarded catch (fish and invertebrates) compared to the standard trawl net types. Average discard ratios were reduced by 1–18% for nine of 12 trawlers, four of which tested mesh escape panels (test: 4–474 kg/tow, standard: 8–665 kg/tow); were similar for one vessel using a mesh panel (test: 3kg/tow, standard: 3kg/tow); and were 2% higher (test: 23–46 kg/tow, standard: 5–24 kg/tow) for two vessels that did not test a mesh panel. Twelve trawlers (six in the North Sea and three in each of the Skagerrak and Baltic Sea) were challenged to reduce discards/unwanted catch of fish and invertebrates in a six-month trial of modified (test) and standard/regulated trawl net gears. Vessels had free choice of gear modifications, which included mesh escape panels, changes to the codend circumference, coverless trawls, separator panels and increases in mesh size (see paper for specifications). Vessels were either twin-rig, towing test and standard nets at the same time, or single-rig and switching between test and standard gears between fishing trips.

A replicated, paired, controlled study in 2013 of seabed areas in the English Channel and southern North Sea, UK (37) found that fish trawl nets fitted with escape sections of square mesh (square mesh cylinders) caught less whiting *Merlangius merlangus* overall, but did not increase the average size of whiting caught, compared with standard diamond mesh trawls without a square mesh cylinder. In two of two comparisons, the numbers of whiting caught were lower in nets with square mesh cylinders (maximum 1,500–3,000 whiting) than standard nets (maximum 4,200–5,000 whiting) (data presented as selectivity distributions), but the average length of the whiting caught was not statistically different (square mesh cylinder: 24.7–25.6 cm, standard: 23.3–25.0 cm). Trials were done in April and November 2013 by commercial trawlers fishing parallel to each other: one rigged with a modified net and the other a standard net. In the first trial on 20–24 m vessels, 15 paired deployments were done with a standard (80 mm diamond mesh with mandatory 80 mm square mesh panel) net modified with an 80 mm section of square mesh around the circumference and a standard net with just the mandatory 80 mm square mesh panel. In the second trial, 13 deployments on 16–20 m vessels tested a net with a square mesh cylinder alone and a standard diamond mesh net without any square mesh (see paper for specifications). Both commercial and non-commercial fish catches were sampled. Total length per fish and weight per species were recorded. Random sub-sampling was done when catches were large.

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2.53 Modify the configuration of a mesh escape panel/window in a trawl net

- **Ten studies** examined the effects of modifying the configuration (position/size and increased mesh size) of a mesh escape panel/window in a trawl net on marine fish populations. Three studies were in the Baltic Sea[5,8,9] (Sweden/Poland). Two studies were in each of the North Sea[2,3] (UK), the Irish Sea[1,7] (UK) and the Kattegat and Skagerrak[6a–b] (Northern Europe). One study was in the Atlantic Ocean[4] (Portugal).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled study in the Baltic Sea[5] found that modifying the position of a mesh escape panel in a trawl net had no effect on the survival rate of cod.

BEHAVIOUR (0 STUDIES)

OTHER (9 STUDIES)

- **Reduction of unwanted catch (5 studies):** Three of five replicated, paired studies (one controlled) in the Irish Sea[1,7], Atlantic Ocean[4] and Kattegat-Skagerrak[6a–b] found that modifying the position[1,6a,7] or mesh size[4, 6b] of a mesh escape panel/window in a trawl net reduced the unwanted catches of whiting in one of two cases[1], haddock and whiting[7], and boarfish[4], but caught similar amounts of horse mackerel and blue whiting[4]. The other studies[6a–b] found that catches of unwanted cod[6a] or other fish[6a–b] were not reduced.
- **Improved size-selectivity of fishing gear (4 studies):** Two of four replicated, controlled studies in the North Sea[2,3] and Baltic Sea[8,9] found that modifying the position and/or size of a mesh escape panel in a trawl net improved size-selectivity of haddock[2,3] and whiting[3]. One of these studies[2] also found that increasing the mesh size of the panel had no effect on size-selectivity for haddock. The other two studies[8,9] found that size-selectivity was similar for cod compared to standard trawls.

Background

Most types of commercial fishing gear catch unwanted fish that are unable to escape before being brought to the surface. To minimise this, escape panels can be fitted to some types of fishing gear, usually traps and trawl nets. Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Fish entering the net will either be retained by it or may escape through the gaps in the mesh of the trawl netting during fishing. Some trawls are fitted with escape panels to allow small fish to escape from the net and avoid being caught. These panels often have square mesh and tend to have larger mesh than the rest of the trawl net. Escape panels need to be positioned correctly, and the positioning depends on which species they are targeting (Suuronen 2005). The mesh size of escape panels, and size of the panel itself, can affect the size, and therefore quantity, of fish that can escape through it.

Evidence for the related intervention is summarized under *'Fishing gear modification - Fit mesh escape panels/windows to a trawl net'.*

Suuronen P. (2005). Mortality of fish escaping trawl gears. *FAO Fisheries Technical Paper*, 478. Rome, FAO. 72p.

A replicated, paired study in 1994–1995 of two areas of seabed in the Irish Sea, UK and Ireland (1) found that trawl nets fitted with a square mesh escape panel located 7 m in front of the codend allowed more undersized whiting *Merlangius merlangus* to escape in one of two cases, compared to trawl nets with a panel 1 m in front of the codend. In twin trawl net deployments, fewer undersized (<27 cm) whiting were caught with the panel 7 m in front of the codend (72 fish/h) than with the panel immediately in front (131 fish/h). However, in parallel net deployments undersized catch was the same (88 fish/h) between trawl designs. Catch of legally sized whiting (>27 cm) was not statistically different between trawl designs in twin trawls (7 m panel: 40, 1 m panel: 50 fish/h) or parallel trawls (7 m panel: 85, 1 m panel: 83 fish/h). In summer of 1994 and 1995, a total of 43 twin and 40 parallel trawl net deployments were undertaken respectively, using two *Nephrops norvegicus* trawl nets fitted with a 3 m square mesh (75 mm) escape panel for 4–5 h each. In one trawl net, the panel was fitted 1 m ahead of the codend, consistent with UK regulations, and in the other trawl net it was fitted 7 m ahead of the codend, consistent with Irish regulations. Each trawl net was 70 mm diamond mesh. Twin trawl nets were towed by a single vessel and parallel net deployments were done by two vessels towing a single trawl each. Full details of the trawl designs are provided in the original paper. All fish caught were identified and the length recorded.

A replicated, controlled study in 1998 of a fished area of seabed in the North Sea, off Scotland, UK (2) found that one of two square mesh escape panels located in the codend of a trawl net improved haddock *Melanogrammus aeglefinus* size-selectivity compared to a panel located in the extension piece or using no panel, but increasing the mesh size of the codend panel had no effect. The length at which haddock had a 50% chance of escaping (selection length) was greater with a square mesh panel of 80 mm mesh located in the codend of the trawl (26 cm), compared to an 80 mm square mesh panel located in the extension piece ahead of the codend (23 cm), and no panel fitted (23 cm). Haddock selection length in a codend panel with a larger mesh size of 100 mm was not significantly higher than the other three cases (30 cm). The authors noted this was probably due to the low catch rates with the 100 mm mesh window. Trials were conducted from a commercial fishing vessel in June 1998, using a twin trawl net. On the starboard side, nets with a 100 mm diamond mesh codend fitted with either a 100 mm square mesh panel, an 80 mm square mesh panel, an 80 mm square mesh panel in the 100 mm diamond mesh extension, or no panel were deployed. A trawl net with a 40 mm codend was towed on the port side. Full details of the trawl designs are provided in the original paper. In total, 16 valid trawl deployments of 60–210 min were completed at 2.6–3.3 knots and 70–81 m depth. Fish were identified and lengths measured.

A replicated, controlled study in 2000 of an offshore seabed area in the North Sea, Scotland, UK (3) found that changing the position of a square mesh escape panel in a trawl net improved haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus* selectivity. The length at which haddock and whiting had a 50% chance of escaping was larger in nets with a square mesh panel located nearest (3–6 m) to the bag of the codend (haddock: 28.2 cm, whiting: 29.4 cm) than when the panel was located further away , (haddock, 6–9 m: 25.1 cm, 9–12 m: 25.5 cm; whiting, 6–9 m: 26.0 cm, 9–12 m: 27.1 cm) or when not using a panel (haddock:, 23.4 cm; whiting:, 25.0 cm). In August 2000, a twin trawl net was deployed with an experimental net on one side and a small-mesh codend net on the other, towed simultaneously. Nine experimental deployments were carried out with a square mesh panel 3–6 m from the cod-line, six with the panel 6–9 m from the cod-line, eight with the panel 9–12 m from the cod-line and nine without a panel. All codends were 100 mm diamond mesh and 100 mesh circumference. Panels were 3 m long with 90 mm square mesh. Fishing took place in the Buchan Deeps in depths of 68–106 m with tow durations of 2.0–3.5 hours. Fish were identified and lengths measured.

A replicated, paired study in 1993–1994 of a seabed area in the Atlantic Ocean off Portugal (4) found that increasing the mesh size of a square mesh escape window in a shrimp separator trawl net reduced the catch of unwanted boarfish *Capros aper*, but not horse mackerel *Trachurus trachurus* and blue whiting *Micromesistius poutassou.* In trials with a 120 mm separator panel, the escape of boarfish increased with increasing mesh size of the square mesh window, with 42% (1,430 kg) of the overall boarfish catch escaping through a 100 mm window compared to 10% (105 kg) with a 70 mm window mesh size. For horse mackerel, escape percentages were similar between window mesh sizes (100 mm: 33%, 70 mm: 34%). In trials with an 80 mm separator panel and 100 mm mesh escape window, boarfish escape was higher (44%) compared to the 120 mm panel with the smaller 70 mm mesh window, but similar to the 120 mm panel with the same size 100 mm mesh window. There were no differences in escape rates between each panel/window codend for horse mackerel or blue whiting (see paper for data). In addition, there were also no differences in escape rate of all three species between a codend with no panel and a 100 mm window alone, and the 70 mm window in the 80 mm panel codend. Percentage escape of the commercial target species rose shrimp *Parapenaeus longirostris* and Norway lobster *Nephrops norvegicus* was similar between mesh sizes with the 120 mm separator panel, however rose shrimp catches varied between the 120 mm and 80 mm mesh panels (see paper for data). Four fishing trials were done in July and September 1993 and May 1994 by research and fishing vessels. In each trial one of four trawl nets was tested: three with different separator panel/escape window mesh size combinations and one with the window alone (see paper for specifications). For each net type, six or seven experimental hauls were done, 26 in total, and catches were retained in the upper and lower codends. Fish escaping through the square mesh window were collected in a small mesh cover mounted over the escape window. Codend and cover catches were sorted by species, weighed and lengths recorded.

A replicated, controlled study in 1998 of seabed in a coastal bay in the Baltic Sea, Sweden (5) found that the survival of cod *Gadus morhua* escaping from trawl nets fitted with two different configurations of square mesh escape panels was similar compared to a standard trawl net with no escape window. Survival of escaped cod was 96–100% from a trawl with a single square mesh panel in the top of the codend, 92–100% from a trawl with two square mesh panels mounted on either side of the codend below the side seams, and 93–100% from a standard trawl with no escape panel. In addition, the number of fish with skin injuries was similar between trawl types (data reported as statistical results). Results where seawater temperatures were relatively high (>9°C) were excluded. In August-September 1998, a total of 19 trawl deployments were done: four with a 105 mm knotless square mesh top panel (Bacoma window) fitted in a standard 120 mm diamond mesh trawl codend, eight with a codend with 105 mm square mesh escape panels on both sides, and seven with a standard trawl net of 105 mm diamond mesh codend. Full gear specifications are given in the original paper. Deployments were carried out on a twin-rig fishing vessel for 3 h each at 30–55 m depth. Cod escaping through the square mesh panels were collected in cages attached to the end of the trawl nets, towed to the seabed and kept in cages for 12–14 days, after which survival and visible skin damage were recorded.

A replicated, paired study in 2003 of seabed areas in the Kattegat and Skagerrak, Northern Europe (6a) found that changing the position of a square mesh escape panel in a Norway lobster *Nephrops norvegicus* trawl net did not reduce the catches of unwanted cod and other fish. The total number of small unwanted cod and the weight of other unwanted fish caught were similar in a trawl with a square mesh panel in the extension piece (ahead of the codend) compared to a square mesh panel in the middle of the codend (cod: 420–423 fish, all other fish: 1,567–1,590 kg). The total number of Norway lobster caught was lower in the trawl with a square mesh panel in the middle of the codend compared to the square mesh panel at the front of the codend (middle: 16,458, front: 19,735 lobsters). In August-September 2003, a total of 24 experimental trawl deployments were conducted in the North Sea by a vessel towing twin 80 mm diamond mesh trawl net codends. One of the two nets had a 90 mm square mesh panel in the top panel of the extension section of the codend (6–9 m from end), and the other had an identical 90 mm square mesh panel in the centre (3–6 m) of the top panel of the codend. Tow duration was 7 hours at a speed of 2.5 knots. All fish were identified and weighed, and the most abundant species were counted.

A replicated, paired study in 2003 on fishing grounds in the Kattegat and Skagerrak, northern Europe (6b) found that increasing the mesh size of a square mesh escape panel in the codend of a Norway lobster *Nephrops norvegicus* trawl net did not typically reduce the amount of unwanted fish. For six of eight target fish species, numbers of unwanted small fish were similar between mesh sizes of the escape panel (90 mm: 391–1,161: 120 mm: 275–666) and lower with the larger mesh size for two species (90 mm: 188, 120 mm: 52). Weight of other unwanted fish catch was similar between escape panel mesh sizes (90 mm: 1,642 kg, 120 mm: 1,833 kg). In addition, nets with a larger escape panel mesh size had a lower overall number (9,739) and a lower number of small Norway lobster (5,168) compared to the smaller mesh size (overall: 10, 738, small: 6,175). In August-September 2003, two diamond mesh codends were tested, one fitted with a 90 mm mesh square mesh escape panel and one with a 120 mm square mesh escape panel. A total of 20 paired trawl deployments were done on a twin-trawl fishing vessel. Catches were sorted into commercial (lengths and weights) and non-commercial (weights) categories.

A replicated, paired, controlled study in 2008–2009 of seabed areas in the Irish Sea, off Northern Ireland, UK (7) found that prawn trawl nets with a modified design and position of square mesh escape panel caught fewer unwanted haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus* compared with the standard trawl design and configuration used in the Norway lobster *Nephrops norvegicus* fishery. The percentage total catch of unwanted haddock and whiting was lower in the trawl with a modified square mesh panel (haddock: 32%, whiting: 26%) than the trawl with a standard panel (haddock: 68%, whiting: 74%). In addition, capture of the target Norway lobster were the same (modified: 50%, standard: 50%). Trials were conducted in October 2008–March 2009 using a twin-rig vessel towing two trawl nets simultaneously. One was an experimental net with two 120 mm square mesh panels located 8.9 m from the codend and separated by a strip of 80 mm diamond mesh 12 meshes wide. The other was a standard 80 mm mesh net with a standard 80 mm square mesh panel 2.1 m from the codend. A total of 16 trawl deployments of 3–4 hours were completed, and nets were regularly swapped between port and starboard sides.

A replicated, controlled study in 2000 of areas of seabed in the Bornholm Deep, Baltic Sea, between Poland and Sweden (8) found that trawl nets fitted with square mesh escape windows either in the bottom or top of the codend did not affect cod *Gadus morhua* selectivity, compared to a standard codend with no square mesh windows. Overall, the length at which cod had a 50% chance of escape was similar between trawl types (bottom windows: 44.6–50.3 cm, top window: 49.3–50.3 cm, no windows: 48.0–49.3 cm). However, this decreased with increasing catch weights in bottom windows in one of two cases, and with no window in one of two cases. In addition, more cod escaped with bottom windows in one of two cases (top: 6,906 fish, bottom: 18,765 fish, none: 13,202 fish) and with a top window in the other case (top: 27,616 fish, bottom: 17,026 fish, none: 16,089 specimens). Trials were conducted on two commercial fishing vessels in April–June 2000. A total of 18 trawl deployments were completed using a trawl net with a 122 mm square mesh top window fitted into a 122 mm mesh codend, 16 tows with two 122 mm square mesh windows fitted into the bottom of a 122 mm mesh codend, and 17 tows using a trawl net with a standard 136 mm mesh codend. Full gear specifications are given in the original paper. Tow duration was 8–11 hours at a speed of 2.5–2.6 knots and depths of 91–95 m. A cover was applied to each codend to retain and sample escaped cod.

A replicated, controlled study in 2012 of a seabed area in the western Baltic Sea, northern Europe (9) found that changing the size and position of a square mesh escape panel in the codend of a trawl net did not increase the likelihood of escape of small Atlantic cod *Gadus morhua*, compared to a standard trawl design with a square mesh panel codend (Bacoma). The length at which cod had a 50% chance of escape was similar in codends with small square mesh panels located either towards the back (30.2–40.3 cm) of the codend or at the front of the codend (30.6–41.7 cm), compared to the standard large square mesh panel codend (35.2–41.8 cm). For three of the four codends with the small square mesh panel at the front, the length at which cod had a 50% chance of escaping was smaller (21.3–41.7 cm) (two codends not tested for significance). Trials were conducted in March/April and September 2012 in the Arkona Basin. A total of 41 alternate haul deployments were done with six separate codends, comprising different combinations of size/position of square mesh panel, one of them the established Bacoma design, the other five with a 50% smaller square mesh panel, four of which had the panel at the front of the codend. A cover was applied to each codend to retain and sample escaped cod. Full gear specifications are given in the original paper. Catches from both the codends and the covers were sorted, and all cod counted and lengths measured.

(1) Armstrong M.J., Briggs R.P. & Rihan D. (1998) A study of optimum positioning of square-mesh escape panels in Irish Sea *Nephrops* trawls. *Fisheries Research*, 34, 179–189.
(2) Graham N. & Kynoch R.J. (2001) Square mesh panels in demersal trawls: some data on haddock selectivity in relation to mesh size and position. *Fisheries Research*, 49 207–218.
(3) Graham N., Kynoch R.J. & Fryer R.J. (2003) Square mesh panels in demersal trawls: further data relating haddock and whiting selectivity to panel position. *Fisheries Research*, 62, 361–375.
(4) Campos A. & Fonseca P. (2004) The use of separator panels and square mesh windows for by-catch reduction in the crustacean trawl fishery off the Algarve (South Portugal). *Fisheries Research*, 69, 147–156.
(5) Suuronen P., Lehtonen E. & Jounela P. (2005) Escape mortality of trawl caught Baltic cod (Gadus morhua) – the effect of water temperature, fish size and codend catch. *Fisheries Research*, 71, 151–163.
(6a–b) Krag L.A., Frandsen R. & Madsen N. (2008) Evaluation of a simple means to reduce discard in the Kattegat-Skagerrak *Nephrops* (*Nephrops norvegicus*) fishery: Commercial testing of different codends and square-mesh panels. *Fisheries Research*, 91, 175–186.
(7) Briggs R.P. (2010) A novel escape panel for trawl nets used in the Irish Sea *Nephrops* fishery. *Fisheries Research,* 105, 118–124.
(8) Madsen N., Tschernih V. & Holst R. (2010) Improving selectivity of the Baltic cod pelagic trawl fishery: Experiments to assess the next step. *Fisheries Research*, 103, 40–47.
(9) Herrmann B., Wienbeck H., Karlsen J.D., Stepputtis D., Dahm E. & Moderhak W. (2015) Understanding the release efficiency of Atlantic cod (*Gadus morhua*) from trawls with a square mesh panel: effects of panel area, panel position, and stimulation of escape response. *ICES Journal of Marine Science*, 72, 686–696.

2.54 Use netting of contrasting colour in a trawl net

- **One study** examined the effect of using netting of contrasting colour in a trawl net on marine fish populations. The study was in the Baltic Sea[1] (Denmark).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Reduction of unwanted catch (1 study):** One replicated, paired, controlled study in the Baltic Sea[1] found that a trawl codend with contrasting black netting used in conjunction with a square mesh escape panel caught a similar amount of undersized cod as a conventional codend.
- **Improved size-selectivity of fishing gear (1 study):** One replicated, paired, controlled study in the Baltic Sea[1] found that two designs of contrasting netting colour in trawl codends with square mesh escape windows did not improve the size-selectivity of cod compared to conventional codend netting colour.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Fish entering the net will either be retained by it or may escape through escape panels, if fitted, or the gaps in the mesh of the trawl netting. Many factors can influence the likelihood of a fish being caught or escaping from a trawl (termed selectivity or efficiency) including species, size of fish, time of day, and trawl configuration. Changing the colour of parts of a trawl net to alter the visibility and contrast of the net to fish could potentially manipulate fish behaviour and likelihood of escape.

A replicated, paired, controlled study in 1995–1996 of bottom fishing grounds in the Baltic Sea, Denmark (1) found that contrasting black netting used in conjunction with a square mesh window in a trawl net codend (three designs) did not reduce catches of undersized Atlantic cod *Gadus morhua* in one case, and did not improve size-selectivity in two cases, compared to trawls with conventional codends of green netting. In a trial of one of three black netting designs, catch numbers of undersized (<35 cm) cod were similar compared to the conventional green (black: 2,030 fish, conventional: 2,184 fish; size-selectivity not calculated). In a separate trial of two other black netting designs, the length at which cod had a 50% chance of escape was similar in one case (32.1 vs 32.7 cm) and smaller in the other (28.2 vs 33.4 cm) compared to the conventional netting. The corresponding numbers of undersized cod caught in these two designs of modified codends compared to the conventional was 746 vs 881 fish, and 672 vs 335 fish, respectively (no statistical result reported). In total, 30 experimental deployments were made in August 1995 and February 1996 around Bornholm, using twin trawls. One trawl was fitted with a green netting codend modified with sections of contrasting black netting (three different designs) to improve fish escape through a square mesh panel, and one with a conventional green codend. Both trawls were fitted with a square mesh panel (compulsory since 1995). Deployments were 175–280 min at 2.7–3.4 knots. Small mesh covers were installed over each codends to collect the escaping fish. Full details of codend designs are provided in the original paper.

(1) Madsen N., Moth-Poulsen T. & Lowry N. (1998) Selectivity experiments with window codends fished in the Baltic Sea cod (*Gadus morhua*) fishery. *Fisheries Research*, 36, 1–14.

2.55 Fit rigid (as opposed to mesh) escape panels/windows to a trawl net

- **One study** examined the effects of fitting rigid escape windows/panels to trawls for fish escape on marine fish populations. The study was in the Baltic Sea[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Reduction of unwanted catch (1 study):** One replicated, paired, controlled study in the Baltic Sea[1] found that fitting rigid escape windows in a section of trawl net reduced the catch of unwanted flatfish compared to a trawl net without escape windows.

Background

Modifying fishing trawl nets is a common practice to improve selectivity, helping fishers to catch only the species and sizes they are commercially targeting. How trawl nets are modified depends largely on the sizes/shapes of the unwanted species and also behavioural characteristics. For example, the avoidance response of some species to trawl gear is to swim upwards, while some may attempt to flee in other directions. The use of panels or windows of modified netting (different orientation and/or mesh size) in trawl net codends has been assessed as one means to allow the escape of unwanted fish (see '*Fishing gear modification – Fit mesh escape panels/windows to trawl nets*'). Rigid escape windows are intended to work on the same principle as mesh escape windows but are specifically designed to enable the potential escape of flatfish species. Unlike mesh windows, rigid escape windows are made of steel and have a grid-like construction that creates well defined rectangular escape openings. They are located with the aim that unwanted flatfish (plus small or undersized roundfish species) can pass through the window in a natural swimming orientation and escape.

A replicated, paired, controlled study in 2013 of an area of seabed in the western Baltic Sea (1) found that a trawl net modified with rigid escape windows in a section of net mounted in front of the codend, reduced the catches of unwanted flatfish compared to a trawl net without rigid escape windows. Total catches of plaice *Pleuronectes platessa* were 56% lower and flounder *Platichthys flesus* 62% lower in the modified trawl compared to standard trawl (windows: 1,033–1,310 fish, no windows: 2,354–3,437 fish). There was no significant difference in overall catches of the commercial target species, cod *Gadus morhua*, in the modified and standard trawls (windows: 1,602 fish, no windows: 1,824 fish) or of undersized cod (windows: 255 fish, no windows: 377). Catch comparison trials were done in March 2013 on a commercial twin trawler on cod fishing grounds west of the island of Bornholm. A total of 12 paired trawl deployments were completed using one modified trawl and one standard trawl net. Both nets were identical and fitted with a mandatory design of selective codend of large square mesh ("Bacoma"). In the modified trawl, rigid grid-like escape windows of 38 mm horizontal bar spacing were incorporated in the two side panels of a four-panel net extension piece in front of the codend ("FRESWIND" system - see paper for specifications). Catches from each haul were weighed by species, and the total length of all fish measured.

(1) Santos J., Herrmann B., Mieske B., Stepputtis, D., Krumme U. & Nilsson H. (2016) Reducing flatfish bycatch in roundfish fisheries. *Fisheries Research*, 184, 64–73.

2.56 Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net

- **Eighteen studies** examined the effects of fitting size-sorting escape grids to a fish trawl net on marine fish populations. Six studies were in the North Sea[1,3,4,9,14,18] (France, Norway, Scotland), three were in the North Atlantic Ocean[6,15,16] (Portugal, USA), and two were in the Norwegian Sea[5,11] (Norway). One study was in each of the Barents Sea[8] (Norway), the South Atlantic Ocean[2] (Namibia), the Mediterranean Sea[7] (Spain), the Adriatic Sea[12] (Italy), the Gulf of Maine[13] (USA), and the Baltic Sea[17] (northern Europe). One study was in a laboratory[10] (Japan).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated study in a laboratory in Japan[10] found that masu salmon were able to actively escape through a rigid escape grid, irrespective of grid orientation and towing speed, but escape was reduced in dark conditions compared to light.

OTHER (17 STUDIES)

- **Reduction of unwanted catch (14 studies):** Eleven of 14 replicated studies (two paired and controlled) in the North Sea[1,3,9,14,18], North Atlantic Ocean[6,15,16] Barents Sea[8] South Atlantic Ocean[2], Mediterranean Sea[7], Adriatic Sea[12] , Gulf of Maine[13] and Baltic Sea[17] found that fitting size-sorting escape grids of various types and configurations to fish trawl nets reduced the catches of unwanted small mackerel[1], small monkfish[2], non-target whiting[3,14] and haddock[3,9,14], small hake[7], unwanted spiny dogfish[13], non-target herring[14], prohibited halibut[15], unwanted sizes of cod[8,17] and other non-target fish[9,15,16], relative to the retained codend catch or compared to trawls without grids. One study[12] found that fitting size-sorting escape grids of three designs to fish trawl nets reduced the discarded catch of nine of 12 fish species and the overall amount of discarded catch (fish and invertebrates combined), relative to the retained codend catch. One study[6] found that fitting size-sorting escape grids had a mixed effect on the reduction of unwanted and/or undersized fish catch relative to the retained codend catch depending on fish ecological group. The other study[18] found that, compared to standard trawl nets without escape grids, trawls with size-sorting escape grids reduced the overall catch of whiting, but not of undersized whiting.
- **Improved size-selection of fishing gear (3 studies):** Two of three replicated studies (two paired and controlled and one controlled) in the North Sea[4] and Norwegian Sea[5,11], found that a size-sorting escape grid fitted to trawl nets improved the size-selection of haddock[4], but not saithe[4] or cod[4,5], compared to standard nets without grids. One study[11] found that trawl nets fitted with an escape grid did not improve the size-selection of cod and haddock compared to trawl nets fitted with square mesh escape windows.

Background

Escape grids are frames of metal, plastics or mesh that are inserted in or near the codend of trawl nets to try and prevent unwanted species or sizes of catch from entering the codend. They are size selection mechanisms, with the sizes at which individuals are sorted dependent on the type of grid and the spacing between the bars of the grid. In some types of grid such as those used in multi-species fish trawls, the aim is to allow smaller fish to escape through the grid and keep the larger marketable sizes of fish. However, in some industrial trawl fisheries (such as for Norway pout), the grid has an opposite purpose of aiming to sort out large fish from the smaller-sized target fish catch. Behaviour of individual fish species may also influence how effective the grid is at allowing escape.

When the fitting of size-sorting escape grids is implemented in prawn/shrimp trawl nets, the evidence has been summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to a prawn/shrimp trawl net*'. Evidence for interventions related to the use of different types or configurations of grids in trawls is summarized under '*Fishing gear modification – Use a different design or configuration of size-sorting escape grid/system in trawl fishing gear (bottom and mid-water)*'. Evidence of this intervention when used in combination with other interventions to reduce unwanted catch in trawl nets is summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to trawl nets and use a square mesh instead of a diamond mesh codend*' and '*Fit mesh escape panels/windows and a size-sorting grid (rigid or flexible) to a trawl net*'.

A replicated study in 1992–1999 of four pelagic areas in the North Sea off Norway (1) found that fish trawls fitted with rigid size-sorting escape grids (three designs) allowed a higher proportion of smaller mackerel *Scomber scombrus* to escape compared to codend catches. Grids of three different designs allowed 8–51% (average 20%) of mackerel of all sizes to escape relative to codend catches (grid: 134–44,000 kg, codend: 128–157,000 kg). The mackerel sorted out by grids had lower average weights (52 to 108 g less) than mackerel retained in the codend and the proportion of mackerel less than 400 g was reduced in all hauls by 4–14% by weight. Data were collected from 12 deployments during separate trials on three commercial and one research vessel from October–December in 1992, 1997, 1998 and 1999. Pelagic mackerel trawl nets were fitted with grids of varying size and construction and either 38 mm (eight tows), 40 mm (two tows) or 42 mm (two tows) bar spacing grid (see paper for specifications). Nets were deployed at 40–142 m depths for 45–140 min. Covers fitted over the grids collected fish escaping through them and a small-mesh inner net in the codend collected the fish that did not escape. Total catch weights in the covers and codend were recorded and subsamples of fish lengths measured.

A replicated study in 2000 of an area of seabed in the South Atlantic Ocean, off Namibia (2) reported that fitting rigid size-sorting escape grids to a fish trawl reduced the amount of unwanted young monkfish *Lophius vomerinus,* relative to the retained catches. Data were not tested for statistical significance. Across four grid designs, 59–68% of the monkfish catch was released through the grids and the vast majority were fish smaller than 31 cm (data reported as length frequency distributions). In addition, of the four grids tested, fewer fish were released by the Sort-V single grid with circular openings of 115 mm (59%) and the EX-it grid with circular openings of 130 mm (61%) compared to the Sort-V single grids with circular openings of 120mm (64%) and 130 mm diameter (68%). Data were collected in February 2000 from 40 trawl deployments of 2 h and in 314–379 m depths. Four rigid sorting grids: an EX-it multiple-panel grid with circular openings of 130 mm diameter and Sort-V single grids with circular openings of 115 mm, 120 mm and 130 mm diameter, were tested in a commercial monkfish diamond mesh trawl net (see paper for specifications). Small mesh covers attached over the grids and inside the codend collected the escaped and retained catches. Fish were sorted and depending on size of catch all, or a subsample, of lengths measured.

A replicated study in 2000 of a pelagic area of the North Sea, Scotland (3) reported that a fish trawl fitted with a size-sorting escape grid system reduced the catch of non-target whiting *Merlangius merlangus* and haddock *Melanogrammus aeglefinus* in an industrial fishery targeting the smaller-sized species Norway pout *Trisopterus esmarki*, relative to the overall catch. Data were not tested for statistical significance. Catches of whiting and haddock were reduced in weight by 57% and 37% respectively by the grid. Almost all whiting sorted out were above the minimum landing size (23 cm), whereas for haddock the main sizes of the fish sorted out were below the 32 cm minimum landing size (data reported as length frequency distributions). Relative to retained catch, losses of fish above the minimum landing size were estimated as 46% for whiting and 9% for haddock. Catches of the target species Norway pout were reported to be reduced by 7%. Data were collected in November/December 2000 from 27 valid trawl deployments on a major Norway pout fishing area in the northern North Sea. An industrial trawl fitted with a hinged grid of 24 mm bar spacing was inserted in front of the codend. The top of the grid was covered by a square mesh window of 108 mm mesh to retain larger marketable fish (see paper for specifications). Covers attached over the top of the grid and the square mesh window collected escaped fish and fish retained by the window. Sub-samples of fish from the two covers and the codend catch were sorted and weighed and fish lengths measured.

A replicated, paired, controlled study in 2001 of two seabed areas in the North Sea off Norway (4) found that fish trawls fitted with a rigid size-sorting grid (Sort-V) improved the size-selection of one of three fish species compared to conventional standard trawl nets. The length at which fish have a 50% chance of escape was higher in codends with a grid compared to conventional codends for haddock *Melanogrammus aeglefinus* (with: 37.2 cm, without: 35.5 cm), but was not statistically different for saithe *Pollachius virens* (with: 49.1 cm, without: 46.4 cm) and Atlantic cod *Gadus morhua* (with: 45.6 cm, without: 40.9 cm). In addition, for haddock, but not saithe or cod, this value increased with increasing catch size in the grid codend but was similar for all catch sizes in the standard codend (data reported as statistical models). Fishing trials were carried out in October 2001 on The Patch and Alle Bank fishing grounds off Bergen. Seven hauls were done with each of two codends: a 120 mm diamond mesh codend fitted with a 35 mm rigid sorting grid and 40 mm guiding panel (Sort V system), and a standard 120 mm diamond mesh codend. Selection (i.e. sizes of fish of each species caught) of each codend was calculated by comparing catch to that caught in a small mesh (50 mm mesh) codend trawled simultaneously.

A replicated, paired, controlled study in 2001 of bottom fishing grounds in the Norwegian Sea off Norway (5) found that a fish trawl net fitted with rigid a size-sorting escape grid did not improve the size-selection of unwanted Atlantic cod *Gadus morhua* compared to a conventional trawl net with no sorting grid. The length at which cod had a 50% chance of escape was similar between trawl nets with a sorting grid (53 cm) and conventional trawls without a grid (49 cm) and the selection range (the difference between the lengths at which 25% and 75% of cod were retained) was 10 cm for both the grid and codend. In addition, the proportion of the 34% of cod below the minimum landing size (47 cm) entering the gear was reduced to 8% in the catches with a grid mounted and 12.0% in the catches without a grid. Data were collected in June and July 2001 west of Bear Island. Trawl deployments were done of a standard 135 mm diamond mesh codend fitted with a stainless steel sorting grid (single grid system - modified Sort-V) with 55 mm bar spacing fitted in the upper trawl panel ahead of the codend (9 tows), and a standard 135 mm diamond mesh codend with no grid (18 tows). Covers over the sorting grid escape opening and the codend retained the escaping catch. Full details of trawl designs are provided in the original study.

A replicated study in 2003 in an area of seabed in the Atlantic Ocean off Portugal (6) reported that fish trawl nets fitted with a size-sorting escape grid (a modified Nordmøre grid system) had a variable effect on the reduction of unwanted and/or undersized fish catch in a multi-species fishery, and the effect differed by ecological group. Data were not tested for statistical significance. In general, unwanted/undersized individuals of three of three bottom-dwelling (demersal) species escaped in higher proportions by number (unwanted lesser-spotted dogfish *Scyliorhinus canicula*: 48%, hake *Merluccius merluccius*: 62%, pouting *Trisopterus luscus*: 79%) than four of four species pelagic species that inhabit the upper water layers (unwanted blue whiting *Micromesistius poutassou*: 13%, unwanted longspine snipefish *Macroramphosus scolopax*: 17%, undersized horse mackerel *Trachurus trachurus*: 14%, undersized Atlantic mackerel *Scomber scombrus*: 0%). Of legally sized commercial species, 10% of hake and horse mackerel, 76% of pouting and 9% of Atlantic mackerel were retained. Data were collected in September

2003 from 17 trawl deployments off the north west coast of Portugal at 40–150 m depths. Trawl nets were fitted with a 1.5 × 1 m plastic grid with 30 mm bar spacing in front of the codend. A 'flapper' net guided catch to the bottom of the grid. The upper 40 cm had no bars to allow catch not sorted out by the grid into the codend. An inner cover fitted over the grid retained catch that passed through the grid and would otherwise escape under commercial operations via an opening in the net (see paper for gear specifications).

A replicated study in 2003 of an inshore area in the western Mediterranean Sea, Spain (7) reported that fitting an experimental size-sorting escape grid to a fish trawl net reduced the capture of unwanted, young hake *Merluccius merluccius* in the hake fishery, relative to the overall catch. Data were not tested for statistical significance. Hake under 21 cm were able to pass through the grid, and the maximum escape rates were for hake under 12 cm, relative to the retained catch not sorted out by the grid (data presented as length frequency distributions and selection curves). Average length at which 50% of hake were retained was 14.2 cm and for all size groups, the escapees accounted for 26% of the hake in weight. In addition, average size-selection range was high, indicating that grid performance was not yet at its best. Data was collected from 10 trawl deployments conducted on a commercial trawler in May 2003. Tow durations were 60–135 min, 3.7 knots and at 40–160 m depths. The trawl net was fitted with a hinged grid 145 x 100 cm, with 20 mm bar spacing in the lower part and four large open rectangles in the top half for larger fish to pass through. Two codends (40 mm mesh) connected to each half of the grid collected the small escaped fish (lower part) and target (large fish) retained (upper part) portions of the catch. Total length of all hake was measured.

A replicated, paired, controlled study in 2002–2003 of bottom fishing grounds in the Barents Sea, Norway (8) found that fish trawl nets fitted with a rigid size-sorting escape grid (Sort-V) reduced the unwanted catch of smaller Atlantic cod *Gadus morhua*, compared to conventional trawl nets without a grid. In two of two trials, the average lengths at which 50% of cod escaped capture and half were retained (selection length) was larger in trawl nets with grids (55 and 54 cm) than without (44 and 50 cm). In 2002–2003, data were collected from experimental trawl deployments off the coast of Finnmark targeting cod. Two sampling methods were used. In 2002, a conventional 135 mm diamond mesh trawl was tested with (17 tows) or without (14 tows) a rigid 55 mm sorting grid. Small-mesh covers installed over the escape outlet of the grid and the codends collected the escaped and retained catch respectively. In 2003, seven paired tows were done with a twin trawler where one side was fished with a conventional 135 mm mesh trawl net with a sorting grid and the other fished with a fine-mesh inner liner. A further nine paired tows were done in the same way with a conventional net without a grid (see paper for specifications).

A replicated study in 1997–1999 of a seabed area in the North Sea off Norway (9) found that fish trawl nets fitted with size-sorting escape grids of various configurations allowed unwanted haddock *Melanogrammus aeglefinus* and other non-target fish to escape capture in an industrial trawl fishery for Norway pout *Trisopterus esmarkii*, relative to the total catch. In 1997 trials, overall percentages of target and non-target fish sorted out by all grid configurations was 13–58%. For the only non-target species with data, haddock, an average of 44% escaped capture and they were significantly smaller than those retained in the codend (data reported as statistical results). In separate trials in 1998–1999 using different grid/net configurations, averages of 25–73% of unwanted haddock, and 65–100% of eight of eight other non-target species (saithe *Pollachius virens*, whiting *Merlangius merlangus*, Atlantic cod *Gadus morhua*, ling *Molva molva*, hake

Merluccius merluccius, mackerel *Scomber scombrus*, herring *Clupea harengus*, tusk *Brosme brosme*) escaped capture. Data were collected from 35 trawl deployments with grids fitted in 1997 and 60 in 1998–1999. In 1997, different guiding panels and grid bar spacings were tested and in 1998–1999 combinations of grid bar thickness and mesh size of netting where grids were inserted were tested (see paper for full specifications). Escaping fish were collected in a cover attached over the escape opening. Cover and codend fish catches were sampled.

A replicated study in a laboratory in Japan (10) found that small masu salmon *Oncorhynchus masou* were able to actively escape through rigid size-sorting escape grids fitted to a finfish trawl, regardless of grid orientation, under simulated trawling conditions, and escape ability was not typically affected by towing speed, but was affected by the light conditions. Across all grid orientations, salmon escape rate through grids was 47–100%. For flat-fitted and forward-sloping grids, more salmon escaped in light conditions compared to dark, regardless of towing speed (light: 87–100%, dark: 47–60%) and for a backward-sloping grid, increasing the speed to 1.5 from 1 knot increased escapes in the dark (to 87% from 67%) so that they were similar to escape rates in the light (100%). In addition, salmon escape through the grids was higher than square mesh panels, for flat and backward-sloping orientations at both light conditions and towing speeds (grids: 47–100%, square meshes: 0–67%) whereas escape through the forward-sloping grids was higher than escaping through the forward-sloping square meshes in the dark at the higher towing speed only. Six trials were conducted for each grid orientation at each towing speed (1 and 1.5 knots), three in dark and three in light conditions. For each trial, five juvenile salmon (12–14 cm length) were released into a circular canal 75 cm wide and 50 cm deep and forced to swim inside a framed net driven around the canal by a motor, to simulate a trawl deployment. The rigid sorting grid (38 mm bar spacing) was fixed to the bottom net frame at three orientations: flat, forward facing or backward facing. Fish were forced to swim for a maximum of 30 min and escapes monitored by video camera. The same trials were done with a square-mesh (60 mm mesh size) panel. The year the study took place is not reported.

A replicated, controlled study in 2005–2006 of two seabed areas in the Norwegian Sea, off Finmark and Troms, northern Norway (11) found that fish trawl nets fitted with a rigid size-sorting escape grid did not improve the size-selection of cod *Gadus morhua* and haddock *Melanogrammus aeglefinnus* compared to trawl nets fitted with square mesh escape windows or a large diamond-mesh codend. In nets with a grid, the average length (56.1 cm) at which half of cod were estimated to be retained (selection length) was similar to nets with escape windows (53.9 cm) but lower than a large diamond mesh codend (60.7 cm). For haddock, average selection length was similar between all three codends: (grid: 50.2 cm, escape windows: 50.6 cm, large diamond: 49.9 cm). In addition, all retention lengths were higher than the minimum landing sizes of 47 cm (cod) and 44 cm (haddock). Data were collected from 62 deployments in December 2005–March 2006 of a trawl net with two codends: one an experimental codend and one a control diamond-mesh codend with a small-mesh inner net. Experimental nets were a 135 mm diamond-mesh codend fitted with a 55 mm sorting grid (Sort-V); a 135 mm diamond-mesh codend fitted with two side escape windows; and a codend of 155 mm diamond mesh.

A replicated study in 2008 of three bottom trawling sites in the North Adriatic Sea, Italy (12) found that fish trawl nets fitted with size-sorting escape grids (Turtle excluder devices) typically reduced the amounts of discarded fish catch and overall discarded catch (fish and invertebrates combined), relative to the codend catch. For three of three designs, grids reduced the average catch rates of nine of 12 discarded fish species (see paper for list of species) compared to the total catch that would have been retained if no grids were fitted (with: 0.17–1.27 kg/tow, without: 0.34–2.45 kg/tow), and for three of 12 fish species average catch rates were similar (with: 0.58–1.16 kg/tow, without: 0.58–1.50 kg/tow). Average catches of all discarded catch (fish and invertebrates) were reduced in nets with grids (with: 9–21 kg/tow, without: 25–28 kg/tow). Three different grid designs (flexible, rigid and semi-rigid construction), all with bottom escape openings, were tested in standard fish trawls used in Mediterranean bottom fisheries (see paper for specifications). Catch data was collected from 42 fishing deployments (11–15 per grid) in March 2008. Fish and marine invertebrates escaping through the grid were collected in a cover attached over the grid outlet. Cover and codend catches were pooled to calculate total catch of a 'control' net without a grid.

A replicated study in 2008–2009 of two bottom fishing areas in the Gulf of Maine, USA (13) reported that experimental rigid size-sorting escape grids fitted to a fish trawl net allowed high proportions of unwanted spiny dogfish *Squalus acanthias* to escape. Overall, more than 88% of spiny dogfish that entered the trawl net were excluded by size-sorting grids, regardless of grid colour or design configuration. However, a black grate with an escape opening in the bottom of the trawl was reported to show the highest dogfish escape ratio (data not tested for statistical difference). Data were collected from 32 deployments of a silver hake *Merluccius bilinearis* trawl during fishing trials in October–November 2008 and July–August 2009. The trawl nets were fitted with a polyethylene grid, with 51 mm bar spacing, inserted into the extension piece in front of a small diamond mesh (51 mm) codend. Different grid colours (black and white), configurations of grid angle (35° and 45°) and location of the escape opening (top and bottom) were tested. Counts of dogfish were obtained from underwater video (mounted in front of the grid) and codend catches.

A replicated study in 2007 of a fished area of seabed in the North Sea off northeast Scotland, UK (14) reported that fish trawl nets fitted with a rigid size-sorting escape grid allowed high proportions of non-target haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus* to escape and around half of all herring *Clupea harengus* in an industrial fishery for the smaller-sized species Norway pout *Trisopterus esmarkii*. Data were reported as percentage escapes and results were not tested for statistical significance. The percentage of haddock and whiting excluded from the trawl by the grid was 93–100% and 81–100% respectively. The percentage of herring that escaped capture was 40–62%. The effect was similar for trawls during the day or night, and for grids facing either forwards or backwards. Loss of target pout was 6–14%. In November/December 2007, data were collected from 14 trawl deployments done on two, nine-day fishing trials on the Fladen Ground, a traditional Norway pout fishing ground. A trawl net fitted with a 180 x 130 cm fibreglass grid with 23 mm bar spacing, mounted at 60° angle, and either facing forwards with a top escape opening (five tows) or backwards with a bottom escape opening (nine tows) was tested. A cover collected catch passing through the escape outlet. Trawls were towed for 8 h at 3.1 knots and 131–144 m depths.

A replicated study in 2011 of a deep seabed area in the North Pacific Ocean off Washington, USA (15) reported that fitting a flexible size-sorting escape grid system allowed the escape of prohibited Pacific halibut *Hippoglossus stenolepis* in a groundfish bottom trawl fishery and, to a lesser extent, unmarketable sizes of other fish species. Data (except halibut length) were not tested for statistical significance. Overall, 62% of the halibut escaped capture through the grid relative to the weight retained in the codend (grid: 308 kg, codend: 192 kg) and they were larger in size (grid: 74.5 cm, codend: 70.0 cm). For the target fish species/groups (see paper for list), between 0–23% of other flatfish, 6–11% of roundfish and 0–77% of skates of unmarketable sizes were sorted out by the grid. In addition, of marketable sizes, an average of 77–87% of other flatfishes, 83–89% of roundfishes and 6–13% of skates of were retained. Trials were carried out using a low-rise flatfish trawl net with a cutback headrope, fitted with a grid system. Data were collected from 30 trawl deployments of 28–30 min, in depths of 113–173 m and at speeds of 2.7–3.2 knots. The grid system was inserted in front of the codend and consisted of two flexible vertical grids (19 ×19 cm openings) to direct fish toward a downward-angled escape panel (see paper for full gear specifications). A cover installed over the escape openings collected escaping fish. Cover and codend catches were sorted and sampled.

A replicated study in 2014 of an area of seabed in the Pacific Ocean off Oregon, USA (16) found that a flexible size-sorting escape grid system fitted to a bottom fish trawl net reduced the catches of non-target fish species, and typically retained much of the targeted flatfish catch. Data were not tested for statistical significance. Overall, catches of five groups and species of non-target roundfish and one flatfish (see paper for list of species), relative to the catches retained in the codend, were reduced by 64–99% (grid: 99–5,372 kg, codend: 16–95 kg), and the probability of escape increased with increasing length. For five target flatfish species evaluated, escape rates were 8–32% (grid: 28–1,164 kg, codend: 268–7,089 kg). In June 2014, a total of 38 trawl deployments were completed west of central Oregon. Hauls were 1 h at an average depth of 174 m. A flexible grid system was fitted to a bottom trawl net, consisting of a four-seam tube of netting inserted in front of the codend (see paper for specifications). The two side panels had 5 x 22 cm grid openings to either exclude fish from the trawl via an exit opening or allow fish to pass through to the codend. A cover net attached over the grid opening sampled escaping fish. All fish caught in the cover net and codend were identified and weighed, and fish lengths sub-sampled.

A replicated study in 2014 of a bottom fishing ground in the western Baltic Sea, northern Europe (17) found that fitting a rigid size-sorting escape grid to a fish trawl net resulted in reduced catches of cod *Gadus morhua* and an increase in the escape of cod of unwanted sizes, in addition to the sizes sorted out by the mesh of the codend. Total numbers of cod that escaped from the net were 3,881 fish (1,608 kg) through the grid and 3,918 fish (1,150 kg) through the meshes of the codend, and the number of cod retained in the codend was 4,715 fish (2,617 kg). In addition, the average length at which half of the cod were likely to escape from each part of the net was 47.9 cm for the grid and 29.7 cm for the codend itself. Data were collected from eight bottom trawl deployments by a research vessel in March 2014 in the Baltic Sea cod fishery. A steel grid, with 50 mm bar spacing, a guiding panel and a top escape opening, was fitted to a standard diamond mesh trawl. A rectangular piece of netting was mounted over the opening to make it less visible to fish and increase fish contact with the grid. Deployments were 90–120 min, towed at three knots. Covers fitted over the grid opening and over the codend collected all cod escaping through them. Cod collected in the two covers and retained in the codend were counted and their lengths measured.

A replicated, paired, controlled study in 2009 of a seabed area in the southern North Sea, France (18) found that a fish trawl net modified with a flexible size-sorting escape grid caught less whiting *Merlangius merlangus* overall but did not reduce the amount of undersized whiting compared to a standard trawl net without a grid, in a mixed-species bottom trawl fishery. Catch numbers of whiting across all lengths were generally lower with a grid, and the most caught of any given length was 7,000 fish with a grid and 10,000 fish without (data not statistically tested). However, average whiting length was not statistically different between nets (grid: 27.3 cm, no grid: 27.5 cm). In February 2009, trials were done on two 20–24 m commercial trawlers fishing parallel to each other: one rigged with the test net and one with the standard net (see paper for specifications). A total of 13 paired deployments were completed. Nets were identical apart from the test net had a 1.25 x 0.75 m flexible grid, and vertical bars with 20-mm spacing, and the standard net had no grid but a mandatory 80 mm square mesh panel. Both commercial and non-commercial fish catches were sampled. Total length/fish and weight/species were recorded. Random sub-sampling was done when catches were large.

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2.57 Fit a size-sorting escape grid (rigid or flexible) to a prawn/shrimp trawl net

- **Thirty studies** examined the effects of fitting size-sorting escape grids to prawn/shrimp trawl nets on marine fish populations. Five studies were in the North Sea[7,9,10,14,21] (Scotland/Norway, Belgium/Netherlands, UK, Scotland), four were in the Coral Sea[3,4,6,26] (Australia) and two were in each of the Gulf of Carpentaria[5,13] (Australia), the Indian Ocean[8,18] (Australia, Mozambique), the North Atlantic Ocean[11,22] (Portugal, USA), the Pacific Ocean[19,23] (Chile, USA), the Skagerrak and Kattegat[20,30] (northern Europe) and the South Atlantic Ocean[24,25] (Brazil). One study was in each of the Tasman Sea[2] (Australia), the Greenland Sea[1] (Svalbard), the Bay of Biscay[15] (France), the Gulf of Maine[16] (USA), the Gulf of Thailand[17] (Vietnam), the Tyrrhenian Sea[27] (Italy), the Gulf of St Vincent[28] (Australia), the Persian Gulf[29] (Iran) and the Northeast Atlantic Ocean[1] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (30 STUDIES)

- **Reduction of unwanted catch (30 studies):** Seven of seven replicated studies (including one controlled) in the northeast Atlantic Ocean[1], North Sea[9], North Atlantic Ocean[11], Greenland Sea[12], Gulf of Thailand[17], Tyrrhenian Sea[27] and the Skagerrak and Kattegat[30] found that fitting rigid or flexible size-sorting escape grids, of various types and configurations, to prawn/shrimp trawl nets reduced unwanted fish catches (non-commercial species and discarded commercial species/sizes) by allowing the escape of unwanted sharks[1,27] and the other fish species monitored[1,9,11,12,17,30]. Two of two before-and-after studies in the Gulf of Maine[16] and Pacific Ocean[19] found that after the introduction of size-sorting escape grids to trawl nets in fisheries for shrimp, the capture of non-target and unwanted fish was reduced compared to before grids were used. Eleven of 20 replicated studies (including one controlled and 19 paired and controlled) in the Tasman Sea[2], Coral Sea[3,4,6,26], Gulf of Carpentaria[5,13], North Sea[7,10,14,21], Indian Ocean[8,18], Bay of Biscay[15], Skagerrak and Kattegat[20], Pacific Ocean[23], South Atlantic Ocean[24,25], Gulf of St Vincent[28] and Persian Gulf[29] found that prawn/shrimp trawls with size-sorting escape grids, of various types and configurations, had lower catches of all or all but one undersized[2,7] or otherwise unwanted fish[5,6,10,21,23,29] and shark/ray[5,13,18,23] species monitored, and unwanted total catch (fish and invertebrates)[6,15,18], compared to trawl nets without escape grids. Two[14,20] found that escape grids reduced non-target catches of most sizes of whiting and plaice[14] and larger sizes of total fish[20], but increased the retention of small cod and haddock[14,20]. Three studies[3,4,24] found a variable effect of fitting escape grids to shrimp/prawn trawl nets on unwanted fish catch compared to nets with no grids, and the effect varied with year[3], site[4] and grid type[24]. Three[8,25,26] found that grids had no effect on the reduction of unwanted fish and catches were similar for all[8,25] or most[26] of the unwanted non-commercial and commercial fish species/groups and for the total unwanted catch (fish and invertebrates)[8]. The other study[28] found that fewer unwanted fish of 10 of 11 species/groups were retained in a shrimp/prawn trawl net with an escape grid used in combination with a diamond mesh codend with the mesh orientation turned by 90°, compared to a conventional diamond mesh net with no grid. One replicated, randomized study in the North Atlantic Ocean[22] found that the reduction in catch of unwanted sharks depended on the type of escape grid and shrimp/prawn trawl net used.

Background

Commercial shrimp or prawn trawl nets are made of small mesh codends that retain the smaller sized crustacean species. But this results in large amounts of other marine animals, like fish, also being caught. The unwanted catch of fish and other large marine animals in shrimp/prawn fisheries has long been considered unacceptable and ways to reduce it have been developed since at least the 1970s (Jenkins 2012). One way is a specialized grid ('bycatch reduction device' or 'turtle excluder device') to exclude fish from the net whilst not losing the commercial catch of shrimps or prawns. The grid is installed in a net at an angle in front of the codend and has an escape opening for fish and other marine animals either at the top or bottom. Grids can be made from metal, plastics or mesh netting and have either vertical or horizontal bars. Grids are designed to work by creating a barrier to fish that are too large to pass through the spaces between the bars and instead they pass out of the trawl net through the escape openings. Grids may also feature guiding panels or other mechanisms to further encourage fish escape and reduce the overall amount of unwanted fish catch.

When the fitting of size-sorting escape grids is implemented in trawl nets targeting fish, the evidence has been summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net*'. Evidence for interventions related to the use of different types or configurations of grids in trawls is summarized under '*Fishing gear modification – Use a different design or configuration of size-sorting escape grid/system in trawl fishing gear (bottom and mid-water)*'. Evidence of this intervention when used in combination with other interventions to reduce unwanted catch in trawl nets is summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to trawl nets and use a square mesh instead of a diamond mesh codend*' and '*Fit mesh escape panels/windows and a size-sorting grid (rigid or flexible) to a trawl net*'.

Jenkins L.D. (2012) Reducing Sea Turtle Bycatch in Trawl Nets: A History of NMFS Turtle Excluder Device (TED) Research. *Marine Fisheries Review*, 74, 26–44.

A replicated study in 1989–1990 of shrimp fishing grounds in the Northeast Atlantic, Norway (1) reported that shrimp trawl nets fitted with rigid size-sorting escape grids allowed small unwanted fish and Greenland shark *Somniosus microcephalus* to escape capture and escape frequency of the small fish increased with fish length. Data were not statistically tested. Trawl nets fitted with an escape grid released more Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* than were retained in the codend and all individuals larger than 20 cm (data were presented as length frequency distributions). For redfish *Sebastes* spp. higher proportions of fish >13 cm escaped than were retained and all redfish >18 cm. For polar cod *Boreogadus saida* higher proportions >14 cm escaped and all were released from 22 cm. All flatfish (including Greenland halibut *Reinhardtius hippoglossoides* and long rough dab *Hippoglossoides platessoides*) >30–32 cm escaped capture, although this larger size compared to other species was due to the species' swimming behaviour. It was also reported that with a grid of at least 1.0 × 1.5 m, Greenland shark up to 4 m escaped relatively easily. In addition, target shrimp *Pandalus borealis* escapes were 2–5%. In 1989–1990, experimental deployments (location and number not reported) were undertaken using trawl nets fitted with an aluminium (Nordmøre) grid mounted at a 48° angle and top escape outlet. Covers mounted over the outlet collected the escaping fish. Two grid designs were used: a coastal (1.35 × 0.7–0.8 m) and an offshore (1.5 × 1.0–1.3 m) grid for smaller and larger vessels respectively. A remote-controlled underwater vehicle monitored fish behaviour. Data from the two grids were combined. Details of study location were not reported.

A replicated, paired, controlled study in 1991 of a seabed area fished commercially for prawns in the Tasman Sea, New South Wales, Australia (2) found that prawn nets modified with a flexible (mesh) size-sorting escape grid (a Morrison soft turtle excluder device) reduced the capture of unwanted finfish compared to unmodified standard nets. Discards of undersized commercial finfish species were significantly reduced in modified nets, however, retained finfish catch was similar (data reported as difference in average log ratio of catch weights). Use of the flexible escape grid did not reduce catches of the target prawn species *Penaeus plebejus* (data reported as difference in average log ratio of catch weights). The weight of discarded finfish and invertebrates combined was an average of 32% (9kg/tow) lower in modified nets than unmodified (not statistically tested). In October 1991, fishing experiments were done on two prawn trawlers, each fitted with three trawl nets in a standard triple gear configuration. Four paired 90-minute deployments using the outer trawl nets only were carried out on each of six consecutive nights. One of the outer nets was modified with a large-mesh (197 mm) escape panel/grid, measuring 36.5 meshes across at the leading edge, installed on the inside of the net. An opening of 20 meshes was cut in the net at the end of the panel immediately in front of the codend to allow larger catch to escape. The other outer trawl net of the three was not modified. Codend catches were separated into retained (prawns and other important species of commercial size) and discarded (rest of catch including undersized individuals of commercial species) portions and weight and lengths recorded.

A replicated, paired, controlled study in 1991–1992 at one coastal seabed and one estuarine site in the Coral Sea, Australia (3) found that using a flexible (mesh) size-sorting escape grid (a Morrison soft turtle excluder device) inside a prawn trawl net resulted in variable reductions of unwanted non-commercial catch (fish and crustaceans) compared to nets without a grid. The reductions in weight (21–32%) of unwanted catch (fish and crustaceans) in nets with a flexible escape grid were significant at both sites in 1991, but not in 1992 (2–18%). In addition, larger unwanted non-commercial catch including stingrays *Amphotistius kuhlii* and shovelnose rays *Rhinobatus batillum* were not caught in nets with a flexible escape grid, but they were occasionally caught in nets without an escape grid (numbers not reported). Prawn catch (*Metapenaeus bennettae, Penaeus plebejus, Penaeus esculentus*) was significantly reduced (17–30%) in nets with a grid at one site in 1991 and both sites in 1992. Paired fishing deployments were done on a research vessel towing two prawn trawl nets at two sites in Moreton Bay off Queensland in May 1991 (low prawn catches) and January 1992 (high prawn catches). A flexible grid made of 150 mm monofilament mesh was installed inside one trawl net and the other net was unmodified. In each year, 17 to 23 deployments of 45–100 min were completed at each site. Codend catches were landed and processed separately.

A replicated, paired, controlled study (year not given) of soft seabed at five coastal sites in the Coral Sea, Australia (4), found that when a catch escape system, incorporating a flexible size-sorting escape grid ('AusTED bycatch reduction device') was fitted to a prawn trawl net, catch of unwanted fish was reduced at three of five sites, compared to a standard trawl net without a grid system. At three sites, fewer (33–59% weight) unwanted fish were caught in nets with grid systems compared to standard nets, whereas at two sites the reduction in weight (11–12%) in nets with grids was not significantly lower. The size (and quality) of the commercial catch of prawns *Penaeidae* was similar between nets (grids: 91–103% of standard net catch). Trials were done using twin prawn nets, one with a grid system and one without, towed simultaneously by a 15 m trawler. In one trawl net, a system incorporating a flexible inclined grid with an escape gap at the top, a large mesh panel and a guiding funnel (AusTED) was installed in front of the codend. Between 13–27 deployments of 60 min were conducted at each of five sites of southeast Queensland. The year(s) the study took place was not reported.

A replicated, paired, controlled study in 1995–1996 of prawn fishing grounds in the Gulf of Carpentaria, Australia (5) found that commercial prawn trawls fitted with size-sorting escape grids (rigid and flexible) typically caught fewer unwanted fish, sharks and stingrays compared to unmodified conventional trawls and the effect varied with grid type. Shark and stingray data were not tested statistically. In two of two experimental trials, two grid types (Nordmøre and AusTED) caught 27–35% less unwanted fish catch than unmodified trawls, but a third grid type (Super Shooter), while reducing unwanted fish catch by 17–21%, was not statistically different. In commercial trials, trawls with grids (Super Shooter and NAFTED) caught fewer sharks (with grids: 3–6, unmodified: 4–16), and stingrays (with grids: 0, unmodified: 0–15). Catches of the target prawn species were similar for two of the grids (Super Shooter and NAFTED) compared to unmodified trawls but were lower for the Nordmøre (50% less) and AusTED (22% less) grids. Fishing trials were carried out in the Gulf of Carpentaria, Australia, in February and October 1995 (experimental) and October 1996 (commercial). Standard prawn trawl nets (45 mm codend mesh) were fitted with one of four grid systems and replicate paired deployments with unmodified trawl nets were conducted by a dual-rigged trawler. Grids had either a top or bottom escape opening, and all had a guiding panel (full details of the grid system designs are provided in the original study).

A replicated, paired, controlled study in 1994 of three areas of sand and mud seabed in the Coral Sea off Queensland, Australia (6) found that prawn trawl nets fitted with a flexible size-sorting escape grid caught less unwanted fish catch and overall unwanted catch (fish and invertebrates combined) than conventional trawl nets with no grid. In one of one comparison in which fish catch was separated from invertebrate catch, nets with a grid caught 15% less fish (2.3 kg/tow) than conventional nets (2.7 kg/tow). In four of four comparisons, grid nets caught 15–49% less unwanted catch (14–50 kg/tow) than conventional nets (17–62 kg/tow). In addition, one shark (species not given) was caught in grid nets compared to three rays *Rhinobatos* spp. in conventional nets (results not tested for statistical significance). Target prawn *Penaeidae* catches were reduced (9–36% lower) in modified nets in two of four comparisons. In 1994, experimental trawl deployments were undertaken at three sites in the Queensland east coast fishery. One codend fitted with an AusTED II (a modification of the original AusTED design) escape grid and one conventional codend were towed simultaneously for 60–180 min. Codend catches were kept separate and the target and non-target portions were sorted and weighed for each net after every tow.

A replicated, paired, controlled study of a seabed area in the North Sea, between Scotland and Norway (7) found that fitting a flexible size-sorting escape grid in a shrimp trawl net typically reduced the catches of undersized cod *Gadus morhua,* haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus* and the overall numbers of Norway pout *Trisopterus esmarki* and saithe *Pollachius virens* but not monkfish *Lophius piscatorius*, compared to trawl nets without an escape grid. In two of two trials, total catch numbers of undersized fish were lower in nets with grids for cod (with: 365–382, without: 1,237–1,805) and haddock (with: 253–579, without: 4,617–5,315). Numbers of undersized whiting were lower in one (with: 15, without: 123) of two (with: 9, without:

11) trials. Overall catch numbers were reduced by 40–55% for Norway pout (two of two trials) and 73% for saithe (one of two trials). Monkfish catch numbers were similar between nets for two of two trials (with: 40–67, without: 43–66). Trials were conducted in the Fladen Ground shrimp fishery onboard a commercial twin-trawler in April–May (20 hauls) and August (30 hauls). A codend fitted with an escape grid was deployed on one side of the gear simultaneously with a standard codend on the other side. A collecting bag caught fish escaping through the grid. The flexible (polyamide) grid was 12 mm diameter bars of 19 mm spacing, fitted at 48° angle, with a fish escape hole at the top and a Norway lobster *Nephrops norvegicus* escape hole at the bottom (see paper for grid specifications). A panel of square mesh netting to retain marketable sizes of roundfish was fitted to the top of the net behind the grid. Fish from the codend and collecting bag were sorted separately into species and lengths recorded. The study year was not reported.

A replicated, paired, controlled study in 2000 of an area of sand/mud seabed in the Indian Ocean, off western Australia (8) found that a prawn trawl net fitted with a rigid size-sorting escape grid did not reduce the catches of seven of seven non-commercial and commercial fish species, or the amount of overall unwanted catch (fish and invertebrates), compared to an unmodified standard trawl net. Average catch numbers of six of six non-commercial and one of one commercial fish species (see paper for individual species data) were similar in nets with a grid to nets without a grid (with: 10–284 fish/tow, without: 5–266 fish/tow) and species weights were also similar (data reported as statistical model results). Average weight of all non-target catch was similar between nets (with: 55 kg/tow, without: 58 kg/tow). In addition, the average weight of all target prawn species *Penaeidae* was reduced (with: 11 kg/tow, without: 13 kg/tow). In August 2000, ten 40-min paired trawl deployments were done on established prawn fishing grounds in Shark Bay. A trawl codend end fitted with an aluminium Nordmøre grid (100 mm bar spacing, 45° angle, top escape opening) was towed simultaneously with a standard codend. All codend catches were sorted, counted and weighed and the species caught in sufficient numbers analysed.

A replicated study in 1996–1997 of bottom fishing grounds in the North Sea off Belgium and the Netherlands (9) found that shrimp trawl nets fitted with a rigid size-sorting escape grid (a Nordmøre grid) reduced the overall amount of fish catch and allowed the majority of undersized fish to escape capture. Across all trials, overall catch numbers of fish species were reduced by 72–75% in nets with a grid compared to without. For four of four species (plaice *Pleuronectes platessa*, sole *Solea solea*, whiting *Merlangius merlangus* and cod *Gadus morhua*) high percentages of the fish escaping through the grid opening were below the minimum landing sizes (data presented as length frequency distributions and selection curves). In addition, catches of undersized and marketable brown shrimp *Crangon crangon* were reduced by 17–45% and 15% respectively. Trawl deployments were made on a research vessel in November 1996 (24 tows) and during three trips on a commercial trawler in July and September 1997 (10 tows). An 8 m commercial shrimp beam trawl net was fitted with an 80 × 60 cm Nordmøre grid and top escape opening. The grid had 12 mm bar spacing in November 1996 and 14 mm spacing subsequently. Covers retained any catch passing through the codend and grid escape opening. All catch (codend and covers) was sorted, counted and lengths recorded. Full trawl details are given in the original study.

A replicated, paired, controlled study in 1993–1995 of two sandy/mud fishing grounds in the North Sea, UK (10) found that fitting rigid size-sorting escape grids inside shrimp trawl nets reduced the catch of unwanted whiting *Merlangius merlangus* and plaice *Pleuronectes platessa*, compared to nets without grids. For three of three designs of grid, total catch numbers of whiting (with: 263–839, without: 586–4,923) and plaice (with: 850–3,074, without 1,304–5,504), were lower in nets with a grid than without, representing 55–85% reductions in catch for whiting and 35–44% for plaice. In addition, for one of one grid designs, the selection length (the length at which fish have a 50% chance of escape) increased with increasing grid bar spacing for both whiting (10 mm: 7.7 cm, 12 mm: 10.5 cm, 14 mm: 11.8 cm) and plaice (12 mm: 9.2 cm, 14 mm: 10.4 cm). Total overall losses (8–10%) of target brown shrimp *Crangon crangon* in nets with grids were not statistically different to nets without grids. Three fishing trials, each testing a different design of grid, were done in the Humber Estuary and off the Lincolnshire coast in November–December and February–March from 1993–1995. Paired trawl deployments (12–22 tows for each grid) were done on commercial shrimp vessels towing a trawl net fitted with a grid and a standard trawl net simultaneously for 0.5–2 h. Grids were made from steel or plastics with 12 mm bar spacings and had top opening escape holes (see paper for full specifications of trawl nets and grids). Two further plastic grids with 10- and 14-mm bar spacings were also tested using a small mesh cover over the grid escape opening to collect the escaping fish.

A replicated study in 2001–2002 of a seabed area in the Atlantic Ocean, off southern Portugal (11) found that prawn/shrimp trawls fitted with a rigid size-sorting escape grid allowed most unwanted blue whiting *Micromesistius poutassou* and boarfish *Capros aper* to escape capture. Data were not tested for statistical significance. Overall, a total of 73–74% in number of blue whiting catch and 47–63% of the catch in number of boarfish, escaped through the grids. Losses of target shrimp species (rose shrimp *Parapenaeus longirostris*, Norway lobster *Nephrops norvegicus* and red shrimp *Aristeus antennatus*) were 4–15%. In May 2001 and April-May 2002 a total of 41 and 15 trawl deployments respectively were carried out on shrimp and Norway lobster fishing grounds off the Algarve. Trawl nets were fitted with a steel grid system (a modified Nordmøre grid) with 25 mm bar spacing, a guiding funnel, top escape opening and a 20 cm high section without bars at the bottom to allow target lobster catch to enter the codend directly (see paper for specifications). The escaping fish were collected in a mesh cover fitted over the escape opening.

A replicated, controlled study in 2002 of two bottom fishing grounds in the Greenland Sea, off western Svalbard, Norway (12) found that shrimp trawl nets fitted with size-sorting escape grids (two designs) allowed high quantities of Greenland halibut *Reinhardtius hippoglossoides,* cod *Gadus morhua,* haddock *Melanogrammus aeglefinus* and saithe *Pollachius virens* to escape capture, but the amounts and sizes of fish released did not differ between grid designs. Average overall reductions in catch weight for four of four species were similar between grid designs (new: 35–184 kg, old: 33–121 kg) representing releases of 81–99% and 69–99% of the fish captured for each grid respectively. The selection length (the length at which fish have a 50% chance of escape) did not differ between grid designs for all four species (new: 14.3–20.2 cm, old: 16.3–19.5 cm). In addition, average catch losses of target Nordic shrimp *Pandalus borealis* were low (4–5%) for both grids. Trials took place in the areas of Ice Fjord and Minke Bank in December 2002 in depths of 240–415 m. Deployments of trawl nets fitted with either a new design of grid (24 tows) made of lighter artificial materials (Cosmos) or an established grid (10 tows) of high-density material (HDPE) were made (see paper for grid specifications). Each grid had 19 mm bar spacings. A top cover collected escaping fish and shrimp. Cover and codend catches of fish and shrimp were weighed and fish lengths recorded.

A replicated, paired, controlled study in 2001 of bottom fishing grounds in the Gulf of Carpentaria, Australia (13) found that prawn trawl nets fitted with rigid or semi-rigid size-sorting escape grids reduced the amount of unwanted shark *Selachii* and ray *Batoidea* catch, but not sawfish *Pristidae*, compared to conventional trawl nets. Across all trawl nets fitted with escape grids, shark and ray catches were reduced by 13% and 31% respectively. Trawl nets fitted with upward-angled grids and top escape openings reduced unwanted shark catch by 20% and rays by 27%, while downward-angled grids and bottom escape openings reduced shark and ray catches by 9% and 35% respectively. No grid system reduced catches of sawfish. Total prawn *Penaeidae* sp. catch was reduced by 6% with grid-modified trawls, except trawls with an upward-angled grid, which caught similar prawn numbers to conventional trawls. Data were collected from up to 1,612 paired trawl comparisons (3,224 nets sampled over 442 nights of trawling) from 23 different vessels in August-November 2001, in which a wide range of catch reduction devices were tested. Nets with escape grids and nets without a grid system installed were towed simultaneously from one randomly assigned side of each vessel. Escape grid designs varied, with no two vessels having the same design. These included 14 downward-excluding grids and nine upward-excluding grids, made either of stainless steel or aluminium and with or without guiding panels/funnels (see paper for specifications). All codend catches were sorted and identified by species, weighed and counted.

A replicated, paired, controlled study in 2005 of a seabed area in the North Sea, UK (14) found that prawn trawl nets fitted with a rigid size-sorting escape grid resulted in less non-target catch of most sizes of whiting *Merlangius merlangus* and plaice *Pleuronectes platessa*, but more small cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*, compared to standard trawls without a grid. Average numbers of whiting (with: 25–126 fish/tow, without: 77–356 fish/tow) in the size ranges 20.6–35.5 cm (98%) and plaice (with: 0–8 fish/tow, without: 1–22 fish/tow) between 20.6–40.5 cm (91%) were lower with the grid than the standard trawl. Fewer cod of marketable size (35 cm) were caught in the trawl net with a grid (with: 0 fish/tow, without: 0–10 fish/tow), but average numbers of small cod (10.6–20.5 cm) were higher (with: 67–120 fish/tow, without: 25–64 fish/tow). More small haddock (10.6–15.5 cm) were caught with the grid (with: 20 fish/tow, without: 14 fish/tow) and catches above this size were typically similar (with: 0–12 fish/tow, without: 0–10 fish/tow). In addition, numbers of marketable sizes of the target species Norway lobster *Nephrops norvegicus* were greater in trawls with a grid (with: 3.8–4.4, without: 3.0–3.9 baskets/trawl) and total discards lower (with: 1.3, without: 1.7 baskets/trawl). In November 2005, a total of 12 paired deployments towing both a standard trawl net fitted with a metal grid (Swedish grid) and a standard trawl net were conducted in the Farn Deeps *Nephrops* fishing ground off the coast of England.

A replicated, paired, controlled study in 2002 of a seabed area in the Bay of Biscay, France (15) found that prawn trawls fitted with an experimental flexible size-sorting escape grid caught less discarded catch (fish and invertebrates) compared to a small-mesh trawl net without a grid. Data were not tested for statistical significance. The amounts of discarded catch (that included large quantities of horse mackerel *Trachurus trachurus* plus debris) were lower in nets with grids in five of six hauls (with: 12–32 kg, without: 14–51 kg) and higher in one of six (with: 59 kg, without: 32 kg). The total amount of discarded catch in all hauls was 161 kg in nets with grids and 184 kg in nets without grids. In addition, grid-fitted nets caught 88% fewer (with: 114 ind, without: 950 ind) undersized individuals of the target species Norway lobster *Nephrops norvegicus*, but also 61% less (with: 1033 individuals, without: 2632 individuals) of marketable size. A total of six, 2.5 h paired trawl deployments were done from a research vessel, simultaneously towing a trawl net fitted with a flexible grid (polyurethane) and a conventional trawl net with a fine-mesh inner lining. The grid had 20 mm bar spacing and was fitted at a 45° angle. Full details of trawl design are provided in the original study.

A before-and-after study in 1991–1996 of a large seabed area in the Gulf of Maine, North Atlantic Ocean, USA (16) found that the requirement to fit a size-sorting escape grid to shrimp trawl nets in a Northern shrimp *Pandalus borealis* fishery reduced the capture of non-target fish compared to the period before grids were introduced. During the four-year period after grids were introduced, averages fish catches (by type) were lower with grids for roundfish (after: 5 kg/hr, before: 11 kg/hr) and flatfish (after: 3 kg/hr, before: 7 kg/hr) compared to the previous two-years and indicated reductions of 59% and 61% for each group respectively. Reductions for individual species ranged from 9% to 62% (see paper for full list of species). In addition, average target Northern shrimp catch increased after grids were used (after: 11 kg/hr, before: 8 kg/hr). Fishery observer data were collected onboard Northern shrimp fishing vessels, fishing up to 182 m depths, during December–March of the 1991–1996 Northern shrimp fishing seasons. A total of 140 vessels were sampled after (643 tows with grids) and before (283 tows without grids) grids were made a requirement in April 1992. Regulatory specifications for the grid were that it must include a rigid or semi-rigid grid of parallel bars spaced no more than 2.54 cm apart, a fish escape opening or hole (top or bottom) in front of both the codend and grid, and a mesh funnel to direct objects to the bottom of the grid (optional in 1994–1996).

A replicated study of an area of shallow water in the Gulf of Thailand, Vietnam (17) found that shrimp trawl nets fitted with a rigid size-sorting excluder grid resulted in the escape of a high proportion of immature unwanted fish and sub-legal sizes of three of three fish of value, in a Vietnamese shrimp *Penaeidae* fishery. Overall, the grid excluded by weight 73% of the immature fish and 16% of the valuable fish catches (data not reported). For three of three fish species of commercial value (Japanese threadfin bream *Nemipterus japonicus,* bartail flathead *Platycephalus indicus* and snakefish *Trachinocephalus myops*) numbers of fish below the 150 mm length minimum landing size were reduced by 70–78% by the grid compared to the total codend catch (grid: 4,885–8,593 fish, codend: 1,767–3,706 fish). Lengths at which 50% of fish escaped were 124–134 mm across the three species. In addition, 8% of the target shrimp species were excluded by the grid. Data were collected over five days from 15 × 3 h trawl deployments at 12–15 m depth near Phu Quoc Island. A grid of three rectangular hinged panels, two of steel construction with 20 mm bar spacing, and one of small mesh to stop fish re-entering the net, was fitted to a 15 mm diamond mesh codend shrimp trawl net. Fish escaping from the grid were collected in a small-mesh cover installed over the panels. Both cover and codend catches were sorted separately by species, weighed and fish lengths recorded. The year the study took place was not reported.

A replicated, paired, controlled study in 2005 of a seabed area in the Indian Ocean, off Mozambique (18) found that fitting a prawn trawl net with rigid size-sorting excluder grids reduced the overall amount of discarded catch (fish and invertebrates) and caught fewer sharks and rays, compared to a conventional trawl without a grid. For two of two grid designs, average catch rates of discards (90% fish, 10% invertebrates) were lower in nets with grids than without (with: 37–48 kg/h, without: 49–83 kg/h). Large sharks and rays were caught in fewer hauls with grids than without (with: 0–2 hauls, without: 4–9 hauls) but there was no statistical difference for smaller sharks and rays (with: 5 hauls, without: 5–9 hauls). In addition, average catches of the target prawn species *Penaeidae* were similar between nets (with: 12–24 kg/h: without: 13–23 kg/h). Trials took place in February 2005 by twin-rigged trawler. A total of 16 paired trawl deployments were done with a net fitted with one of two grid designs (both Nordmøre) and a conventional trawl without a grid. Grids were aluminium, 100 mm bar spacing, fitted with a guiding funnel either with or without a cover flap in front of the grid escape opening (see paper for specifications). Codend catches were sorted into commercial/non-commercial portions, counted and weighed, and lengths of selected species measured.

A before-and-after study in 1981–2005 of an area of seabed in the Pacific Ocean off the coast of Oregon, USA (19) found that the requirement to use rigid or flexible (mesh) size-sorting escape grids in shrimp trawl nets led to an overall reduction in catches of unwanted fish in an ocean shrimp *Pandalus jordani* fishery, compared to historical pre-use levels. Data were not tested for statistical significance. For four different types of escape grid, the amount of unwanted fish catch in the period after grids were introduced (2002–2005) was 6.5–13.3% of the total catches, compared to 32–61% unwanted fish catch in the years before grids were introduced (1981–2000). In 2005, catches of unwanted fish were 77–88% lower than the years from 1981–2000. In addition, catch rate and percentage of unwanted catch was significantly related to grid type and bar spacing (see paper for grid types). The use of a rigid or soft-mesh escape grid device to reduce unwanted catch was fully mandated in the ocean shrimp fishery in 2003 but grids were in use prior to this. Fisheries catch data post-grid use were collected in 2002–2005 by observers deployed on vessels operating in the fishery off the coast of Oregon. Historical catch data from 1981–2000 for nets without a grid or panel, were obtained from published and unpublished research sampling and survey records. See paper for list of fish species caught.

A replicated, controlled study in 2005 of a seabed area in the Skagerrak and Kattegat, northern Europe (20) found that fitting a rigid size-sorting escape grid to prawn trawl nets reduced the catches of larger-sized fish of all species but increased the retention of small cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*, compared to a standard diamond mesh codend without a grid. Overall, total catch numbers of legal sizes of eight of eight fish species (see paper for full list of species and minimum landing sizes) were lower in the net with a grid (with: 1–229 fish, without: 57–3,283 fish) (data not statistically tested). Catch numbers were significantly lower for cod, haddock, whiting *Merlangius merlangus* and plaice *Pleuronectes platessa* smaller than legal size but longer than 25, 20, 17 and 22 cm, respectively (data not reported). Numbers of fish were significantly higher in the net with a grid for small sizes of cod between 10–19 cm and haddock between 11–15 cm (data not reported). In addition, retention of the target prawn species *Nephrops norvegicus* longer than 41.8 mm was significantly lower with a grid than without (data presented as retention probability curves). In September and October 2005, trials were done by commercial fishing vessel using twin-trawl net gear. Trawl deployments were carried out with a small mesh (40 mm) codend paired with either: a standard 90 mm diamond-mesh codend fitted with a steel grid (22 hauls) or a standard 90 mm unmodified codend (18 hauls). The grid was 35 mm bar spacing in the lower quarters and 80 mm spacing in the upper quarter (see paper for specifications).

Catches in each codend were sorted by species and weighed. Total length was measured for commercially important fish species and carapace length for *Nephrops*.

A replicated, paired, controlled study in 2009 in two areas of seabed in the North Sea, Scotland (21) found that prawn trawls fitted with a rigid size-sorting escape grid caught fewer unwanted fish species compared to an unmodified reference trawl. A trawl net fitted with a grid caught lower overall numbers of six of six unwanted fish species (hake *Merluccius merluccius,* cod *Gadus morhua*, haddock *Merluccius aeglefinus*, whiting *Merlangius merlangus*, plaice *Pleuronectes platessa* and witch *Glyptocephalus cynoglossus*) than the unmodified trawl (data reported as statistical model outputs). In addition, overall catch rates of the target species Norway lobster *Nephrops norvegicus* were similar between trawl nets, but fewer lobster of legal landing size (> 41 cm) were caught in nets with a grid (data reported as statistical model results). In March and July 2009, a total of 22 paired trawl deployments were carried out in the South Minch and Fladen Grounds near Scotland, respectively. One trawl net (80 mm codend) fitted with a 1.52 × 0.36 m aluminium grid (Swedish grid) was towed simultaneously with a conventional trawl net with a small-mesh (40 mm) codend. The grid had 35 mm bar spacing, top escape opening and was positioned at a 45° angle 13 m in front of the codend. Trawls were deployed for 3–3.5 hours in depths 108–139 m and all catch counted, and lengths measured.

A replicated, randomized study in 1995–1998 at multiple coastal sites in the Atlantic Ocean, USA (22) found that the amount of unwanted shark catch in shrimp trawls fitted with a rigid size-sorting escape grid depended on the type of trawl net and grid used. Commercial mongoose and flat net shrimp trawls fitted with two types of rigid grids with bottom escape openings (Super Shooter or Georgia Jumper respectively) caught fewer unwanted sharks *Elasmobranchii* (2/h) than triple wing shrimp trawl nets fitted with only Super Shooter grids (23/h). Shark catch rates in mongoose trawl nets fitted with Super Shooter grids were not statistically different to other gear combinations, both with and without an additional supported escape opening (Fish Eye) in the codend (with: 15/h, without: 17/h). In addition, the duration and towing speed of the trawl deployments did not affect shark catch rates (data reported as statistical model results). From April 1995–January 1998 (except February and March each year) shrimp trawl discard data were collected by fishery observers onboard vessels in the penaeid *Penaeidae* shrimp fishery off Georgia. Vessels randomly selected one of three commercial shrimp trawl net designs to use: flat net, mongoose or triple wing trawls. Each was fitted with a 'Super Shooter' escape grid, except some mongoose nets that used a 'Georgia Jumper' grid. Both grid types were metal and oval, but differed in the angle of the bars. Some mongoose net/Super Shooter combinations also included a 'Fish Eye' escape opening in the codend. Full details of trawl and grid designs are provided in the original study.

A replicated, controlled study in 2008–2009 of a seabed area in the Pacific Ocean off Chile (23) found that shrimp trawl nets fitted with a rigid size-sorting escape grid allowed more unwanted fish to escape capture than conventional trawl nets with no grid. The total percentages in number of unwanted catch (fish and invertebrates combined) that escaped capture was higher in trawls with a grid fitted (25%) than in trawls without a grid (2–3%). The percentage number of catch that escaped capture was also higher in trawls with a grid fitted than trawls without a grid for Chilean hake *Merluccius gayi gayi* (48 vs 1%), Aconcagua grenadier *Coelorinchus aconcagua* (20 vs 0–3%), cardinalfish (Apogonidae) (80 vs 1–4%) and elasmobranchs (Elasmobranchii) (39 vs 0%). Escapees were similar in trawls with and without a grid for cusk-eel *Ophidiidae* (100 vs 94%). Thirty-nine trawl deployments were made using two trawl nets with 56 mm diamond mesh codends, either with or without a rigid grid. The grid was a metal Nordmøre grid (1.2 × 0.8 m) with 35 mm bar spacing and top escape opening, fitted at a 45° angle in front of the codend. A mesh guiding panel guided catch to the grid. Covers over the grid opening collected the escaping catch. All codend and cover catches were sorted and weighed separately.

A replicated, paired, controlled study in 2007–2009 of a seabed area in the southern Atlantic Ocean, Brazil (24) found that only one of four designs of rigid size-sorting escape grids (Nordmøre grid) fitted to shrimp/prawn nets reduced the amount of unwanted fish catch in an artisanal canoe-trawl fishery, compared to nets without a grid. Average weight of unwanted fish catch was reduced by 50% in nets fitted with a small grid compared to no grid (with: 1.2 kg/tow, without: 2.5 kg/tow) but was similar for three other larger grid designs (with: 1.0–1.2 kg/tow, without: 1.5 kg/tow). Catch of the target species Atlantic seabob *Xiphopenaeus kroyeri* was similar for four of four grid designs (with: 1.7–3.9 kg/tow, without: 0.9–4.5 kg/tow). Two trials were done between July 2007 and November 2009 off the coast of Paraná. A total of 18 (small grid, 60 min tows) and 12 (three large grids, 30 min tows) paired deployments of two trawl nets, one with a grid and one without, were done from a motorized canoe. Four configurations of aluminium grids (Nordmøre) were tested; all with 24 mm bar spacing, but differing in size/weight (one small, three larger), bar type, presence or absence of a guiding panel and mesh size of the extension piece of netting (see paper for specifications). Trawl nets were randomly deployed on each side of the canoe. Codend catches were separated by species and the numbers and weights of fish recorded.

A replicated, paired, controlled study in 2010 of a sandy seabed area in the Atlantic Ocean, off Brazil (25) found that shrimp trawl nets fitted with rigid size-sorting escape grids (Nordmøre) did not catch fewer unwanted fish in a canoe-trawl fishery, compared to conventional trawls with no grids, regardless of grid bar spacing. For three of three grid bar spacings, the average catch weight of all unwanted fish (see paper for list of species) was similar between trawl nets (grid: 1.0–1.3 kg/30 min, no grid: 1.2 kg/30 min). Numbers of four of four fish species with sufficient data were similar between nets (grid: 8–55 fish/30 min, no grid: 6–35 fish/30 min), but trawls with grids retained smaller sizes of two of those species (grid: 8.0–8.4 cm, no grid: 8.9–9.0 cm). In addition, there was no significant difference in the weights of retained target seabob shrimp *Xiphopenaeus kroyeri* catches (grid: 5.0–5.4 kg/30 min, no grid: 4.8 kg/30 min). In April–June 2010, data was collected from 24 paired deployments of each of six net pairings, towed in <15 m depth by a motorized canoe rigged with two identical trawls. Three conventional trawl nets were fitted with aluminium Nordmøre grids with 17-, 20- or 24 mm bar spacings and tested against each other and against one conventional net without a grid (see paper for specifications). Codend catches were counted and weighed by species.

A replicated, paired, controlled study in 2002 of a coastal seabed area in the Coral Sea, Australia (26) found that prawn trawl nets fitted with a rigid size-sorting escape grid (turtle excluder device) did not reduce the amount of unwanted fish catch, compared to a standard diamond mesh trawl codend. For one of 26 unwanted fish species with data (see paper for list of species), the average catch rate was lower with a grid than without (with: 94.7 g/h, without: 134.3 g/h) but for the remaining, average catch rates were either similar (23 species) or higher (two species) between nets (with: 1.3–95.7 g/ha, without: 1.1–72.2 g/ha). In addition, catch rates of the target eastern king prawns *Melicertus plebejus* were similar between nets (with: 291.1–274.4 g/ha). In July 2002, data were collected from 65 paired trawl deployments done over ten nights off the coast of

Queensland. Three different codends were tested against a standard diamond mesh codend: a standard diamond mesh with a metal, top-opening grid (Wick's turtle excluder device), a grid in combination with a square mesh codend, and a square mesh codend alone (see paper for specifications). Each codend design was randomly assigned to the two trawl nets every 12 tows. Each tow was two nm long, at 2.2 knots.

A replicated study in 2012 of a seabed area in the Tyrrhenian Sea, western Mediterranean (27) found that a prawn trawl fitted with a rigid size-sorting escape grid allowed a small proportion of unwanted blackmouth catshark *Galeus melastomus* of larger size to escape capture. In number, 182 catshark escaped through the grid, 263 escaped from the codend and 540 were retained in the codend. Catshark larger than 45 cm total length were more likely to escape through the grid and the estimated length at which half would escape was 53 cm, whereas individuals smaller than 20 cm were more likely to escape from the codend (data reported as probability/selection curves). In addition, for two of two commercial species, the grid-fitted trawl codend retained 39% and 94% of greater forkbeard *Phycis blennoides* and Norway lobster *Nephrops norvegicus* respectively. A conventional (50 mm diamond mesh codend) commercial bottom trawl net used in Mediterranean was fitted with an aluminium "Super Shooter" grid with 90 mm bar spacing, located 3.5 m in front of the codend at a 45° angle. Data were collected from six trawl deployments in April and July 2012. Two covers with 20 mm mesh were attached over the grid escape opening and the codend to collect escaped individuals. Total catch was sorted and weighed and fish lengths recorded.

A replicated, paired, controlled study in 2012 in the Gulf St Vincent, Australia (28) found that prawn trawls modified with a rigid size-sorting excluder grid, and a diamond mesh codend with the mesh orientation turned by 90°, caught fewer unwanted fish compared to conventional diamond mesh nets with no grid. Modified trawls caught fewer unwanted individuals than conventional trawls of rays *Batoidea* (2.6 vs 0.7/h), sharks *Selachii* (2.0 vs 0.3/h), porcupinefish *Diodontidae* (0.8 vs 0.0/h), bream *Sparidae* (0.2 vs 0.0/h), armourheads *Pentacerotidae* (0.1 vs 0.0/h), croaker *Sciaenidae* (0.1 vs 0.0/h), filefish *Monocanthidae* (22.4 vs 10.8/h), jacks and pompanos *Carangidae* (2.8 vs 2.2/h), dragonets *Callionymidae* (2.3 vs 1.0/h) and gurnard *Triglidae* (2.2 vs 1.3/h). Numbers of flatheads *Platycephalidae* caught in each trawl design were similar (data reported as statistical model results). Target western King prawn *Penaeus latisulcatus* catches were 15% lower in modified trawls (results not tested for statistical significance), although this was largely due to losses of small, low-value individuals. Twenty-nine, 30-min, replicate paired trawl deployments were undertaken at randomly chosen sites in May 2012 using modified and conventional trawl nets. Modified nets were fitted with a U-shaped plastic grid with 50 mm bar spacing and top escape opening and had a codend of 58 mm diamond mesh rotated 90° in orientation. Conventional trawls used 58 mm diamond mesh codends. Full details of trawl design are given in the original study.

A replicated, paired, controlled study in 2013 of shallow, coastal waters in the Persian Gulf, Iran (29) found that shrimp trawl nets fitted with a rigid size-sorting escape grid (a Nordmore grid) caught fewer undersized fish compared to a trawl net without a grid. The net with a grid caught lower proportions of undersized individuals of three of three fish species: narrow-barred Spanish mackerel *Scomberomorous commerson* (with: 11%, without: 36%), tigertooth croaker *Otolithes ruber* (with: 29%, without: 43%) and silver pomfret *Pampus argenteus* (with: 13%, without: 15%). For each species, the length at which half were likely to escape was smaller than the minimum landing sizes. In addition, compared to a 32% reduction in average exclusion rate of undersized fish with a

Nordmore grid, a trawl net fitted with a different design of grid (Nafted) and an additional large supported escape opening (Fisheye), reduced the undersized catches by 47%. Data were collected from a total of 30 valid trawl deployments (15 tows for each grid design) conducted by a commercial vessel in 2013. Test trawl nets fitted with grids were towed for 1.5 h alongside nets without grids in depths of 13–33 m. Codends were all of 30 mm mesh size. Both the Nordmore and Nafted grids had 60 mm bar spacing at were fitted at a 45° angle. The Nafted grid was fitted in combination with a Fisheye escape opening, a steel frame sewn into the top of the codend to provide an elliptical opening of 400 mm for fish escape.

A replicated study in 2010 of a seabed area in the Kattegat and Skagerrak, North Sea, bordering Norway, Denmark and Sweden (30) found that size-sorting escape grids of three designs fitted to prawn trawl nets all reduced the capture of unwanted small fish in a Norway lobster *Nephrops norvegicus* fishery. Overall, grids enabled 55–88% (225–6,766 fish) of undersized individuals of three of three roundfish (cod *Gadus morhua,* haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus*) and 35–86% (337–3,463 fish) of undersized fish of two of two flatfish (lemon sole *Microstomus kitt* and plaice *Pleuronectes platessa*) to escape. In addition, grids reduced the catches of undersized individuals of the target Norway lobster by 5–17%, but there were losses above minimum landing size of 13–33%. Data were collected from 10–14 trawl deployments of 2–4 h at 42–71 m depth, for each of three grid systems in March 2010 using a twin-rigged trawler. Trawl nets of 90 mm mesh codend were fitted with grid systems of either: horizontal bars, vertical bars, or vertical bars and a mesh guiding panel. All grids were black in colour, 45 mm bar spacing, set at 45° angles and with a hole at the bottom part to stop debris (see paper for specifications). Small mesh covers attached over the grid escape opening collected fish escaping through the grid. Cover and codend catches were weighed and length measurements taken for all commercially important species.

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2.58 Fit a size-sorting mesh funnel (a sieve net) to a prawn/shrimp trawl net

- **Three studies** examined the effects of fitting a size-sorting mesh funnel (sieve net) to a prawn/shrimp trawl net on marine fish populations. All three studies were in the North Sea[1,2,3] (Belgium, England).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR RESPONSE (0 STUDIES)

OTHER (3 STUDIES)

- **Reduction of unwanted catch (3 studies):** Three replicated, paired, controlled studies in the North Sea[1,2,3] found that shrimp trawls fitted with a mesh size-sorting funnel, a sieve net, reduced the catches of unwanted (non-commercial or discarded) fish, compared to standard trawls.

Background

Trawling is considered a non-selective method of fishing as large proportions of fish that enter the gear may be retained in the net. To help reduce the capture of unwanted fish, a sieve net (a "bycatch reduction device") can be used to help sort the catch into different species or sizes and allow the escape of some. A sieve net is attached to the full circumference of prawn or shrimp trawl nets and tapers to an apex near the trawl's codend. An exit opening is made where the sieve net and codend join, allowing fish and other larger animals to pass through the sieve and escape, whereas the shrimp pass through the sieve and into the codend (Revill & Holst, 2004). Mesh sieve or sorting panels work in a similar manner, intending to separate unwanted species from prawn catches by mechanical and behavioural means (Santos *et al.* 2018).

Evidence for a similar intervention relating to prawn/shrimp trawl nets is summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to a prawn/shrimp trawl net*'.

Revill A. & Holst R. (2004) The selective properties of some sieve nets. *Fisheries Research*, 66, 171–183.
Santos J., Herrmann B., Mieske B., Krag L.A., Haase S. & Stepputtis D. (2018) The efficiency of sieve-panels for bycatch separation in *Nephrops* trawls. *Fisheries Management and Ecology,* 25, 464–473.

A replicated, paired, controlled study in 2000–2001 of a seabed area in the Flemish Banks in the North Sea, Belgium (1) reported that shrimp trawls fitted with a sieve net reduced the catches of unwanted non-commercial fish compared to a standard trawl net without a sieve net. For non-commercial fish species, the average percentage reduction in catch with a sieve net compared to without was: 49% for gobies *Pomatoschistus* spp., 45% for dragonets *Callionymus* spp., 76% for seasnail *Liparis liparis*, 35% for pogge *Agonus cataphractus,* 61% for bullrout *Myoxocephalus scorpius*, 37% for pipefish *Syngnathus* spp., 61% for five-bearded rockling *Ciliata mustela*, 22% for pout *Trisopterus luscus* and 99% for anchovy *Engraulis encrasicholus*. In addition, the sieve net showed poor size-selectivity for all commercial fish species with lengths below 10 cm (i.e. lower escape rates), however >10 cm the selection improved with increasing length (see paper for data). Target brown shrimp *Crangon crangon* catches were reduced by ≤15%. Data were collected from 72 trawl deployments on a commercial fishing vessel between April 2000 and January 2001. Paired deployments (one on each side of the vessel) were done of two standard design shrimp beam trawls (20 mm codend mesh); one fitted with a 70 mm mesh sieve net (116 meshes wide at the front and 16 at the rear, 60 meshes deep) with an escape outlet in the lower trawl body ahead of the codend (see original paper for specifications). A small mesh (11 mm) cover attached over the escape opening collected catch escaping through the sieve net escape. Sub-samples of non-commercial fish catch in the cover and codend was weighed and counted.

A replicated, paired, controlled study in 1999–2000 of bottom fishing grounds in the North Sea, England, UK (2) found that shrimp trawl nets fitted with a sieve net (four designs) caught fewer unwanted fish compared to a conventional trawl without a sieve net. Across all four sieve net designs, average catch numbers of unwanted fish were lower in trawls with a sieve net compared to without, for: plaice *Pleuronectes platessa* (with: 9–

15 fish/haul, 12–21 fish/haul), dab *Limanda limanda* (with: 14–35 fish/haul, 8–55 fish/haul) and whiting *Merlangius merlangus* (with: 64–133 fish/haul, 73–151 fish/haul). In addition, overall discarded catch (fish and invertebrates combined) was reduced in sieve nets by 56–90% in weight, and losses of target brown shrimp *Crangon crangon* ranged between 8–21%. Paired deployments were undertaken in The Wash fishing grounds using standard shrimp trawls (20 mm mesh codend) fitted with one of four sieve net designs (see original paper for specifications) and standard shrimp trawls without sieve nets. Trawls were towed at 2–3 knots for 1 h and 480 tows were completed.

A replicated, paired, controlled study in 2006–2007 of two inshore areas of seabed in the North Sea, England, UK (3) found that shrimp trawl nets fitted with a sieve net reduced the catches of unwanted fish compared to trawls without sieve nets. The average weight of unwanted fish catch was lower in trawls with sieve nets than those without (with: 6 kg, without: 11 kg). In addition, unmarketable small brown shrimp *Crangon crangon* and marketable shrimp catches were reduced with sieve nets by 8% and 14% respectively (with: 22–24 kg, without: 27–30 kg). Sampling was done between January 2006 and 2007 at two coastal sites from five commercial vessels fishing with twin beam trawls. Two beam trawls, were fished simultaneously; one with a sieve net and one without and data collected for 98 valid deployments. The catches from each trawl net was sorted into marketable and non-marketable sizes of shrimp and fish, counted and weighed.

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2.59 Fit large, supported escape openings (such as Fisheyes, Bigeyes and radial escape sections) to trawl nets

- **Eight studies** examined the effects of fitting large, supported escape openings (such as Fisheyes, Bigeyes and radial escape sections) to trawl nets on marine fish populations. Three studies were in the northwest Atlantic Ocean[1,6,8] (USA) and three were in the Gulf of Carpentaria[2,3,5] (Australia). One study was in the north Pacific Ocean[7] (USA) and one was in the Coral Sea[4] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (8 STUDIES)

- **Reduction of unwanted catch (8 studies):** Six of seven replicated studies (five paired and controlled, and one randomized, paired and controlled) in the Atlantic Ocean[1,6,8], Gulf of Carpentaria[2,5], Pacific Ocean[7] and the Coral Sea[4] found that fitting large, supported escape openings (various designs including Fisheyes, Bigeyes and radial escape sections) to trawl nets reduced the overall catches of unwanted fish[1,2,6], immature red snapper[8] and total unwanted catch (fish and invertebrates combined)[4,5] compared to standard nets. The other study[7] found that there were fewer unwanted Chinook salmon in catches with two of two designs of escape openings, but only one of the designs caught fewer widow rockfish. One replicated, paired and controlled study in the Gulf of Carpentaria[3] found that trawl nets fitted with either large escape openings or a square mesh escape panel reduced unwanted shark catch but not unwanted ray or sawfish catches, compared to standard nets.

Background

Large, supported openings in trawl nets are catch reduction devices consisting of a large slit or hole, held open by floats and weights (e.g. Bigeye) or by supporting frames (e.g. Fisheye). They are typically used in prawn/shrimp trawls with the aim of allowing unwanted fish catch to escape while retaining the target crustacean species. Unlike other escape devices used in prawn/shrimp trawls such as size-sorting grids, these devices work by exploiting the behaviour of fish that are able to swim back and escape through the exit openings. Here, we also include radial escape sections that consist of a section of multiple large rigid openings running around the circumference of the net, because they too enable fish that can swim forward away from the codend to escape through the openings, unlike the prawns/shrimps. Use of large, supported openings in trawls potentially facilitate the escape of unwanted fish, including immature small fish, from the codend. They may also be used in addition to size-sorting escape grids to further increase the overall selectivity of the trawl net by providing another area for fish escape.

Evidence of the effect of this intervention when used in combination with another intervention to reduce unwanted catch in trawl nets is summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) and large supported escape openings to trawl nets*'.

A replicated, paired, controlled study in 1993 of three coastal seabed areas in the Gulf of Mexico, USA (1) found that shrimp trawl codends fitted with large, supported openings (single or radial), reduced the unwanted fish catch compared to unmodified codends without escape openings. For seven of eight different designs of escape opening devices, fish catch was reduced by 22–55% in number (with: 74–248 fish/tow, without: 124–422 fish/tow), and by 27–62% in weight (with: 1,127–2,750 g/tow, without: 2,152–5,530 g/tow). One of eight designs had a 50% lower weight of unwanted fish than a net without escape openings (with:1,245 g/tow, without: 2,489 g/tow) but catch numbers were similar (with:177 fish/tow, without: 170 fish/tow). Target commercial shrimp *Penaeidae* catches were reduced by 5–39% in number (5–35% in weight) across all eight designs of escape opening devices, however three were not statistically different to catches without a device. Data were collected in spring and autumn 1993 during the shrimp fishing seasons from 36 twin trawl deployments (12/area/season). They were done using a net with one of four designs of supported escape openings towed simultaneously with an unmodified net. In the autumn, modified versions of each of the original four escape opening designs were tested in the same way. Escape opening devices consisted of either a single large, framed opening or a section of large mesh openings running around the net circumference. Each design also had a mesh guiding funnel inside the net leading to the escape sections (see original paper for full specifications). Fish and shrimp in each codend were identified, counted and weighed in the laboratory.

A replicated, paired, controlled study in 1995 of a fished area of seabed in the Gulf of Carpentaria off Australia (2) found that prawn trawl nets fitted with one of two designs of large, supported escape openings (single or radial) typically reduced the catch of unwanted fish compared to unmodified standard trawl nets. Compared to catches in the standard net, average catch weights of unwanted fish in nets fitted with a radial cylinder design of escape opening were lower in two of two trials, by 20–40%. Unwanted catch of fish in trawl nets fitted with a single escape opening (Fisheye) were similar by weight between trawls in three of three cases (69–90% of the unwanted fish catch in standard catches). Catch weights of commercial target prawns *Penaeidae* in trawls fitted with the radial escape section were similar in one of two cases with the radial cylinder escape design relative to the standard and reduced by 12% in the other. The Fisheye system caught similar weights of target prawns in three of three cases. Data were collected in scientific trials in February (two trials) and October 1995 from deployments of standard twin trawl prawn nets (45 mm codend mesh). Nets were fitted on one side with one of two designs of large, supported escape openings and towed simultaneously with unmodified trawls or other combinations of net designs also being tested (see original paper for full gear specification). A total of 29 hauls (30 min or 2 h) were made with the radial escape design, 28 hauls with the Fisheye escape design and 71 with the standard trawl. Fish and prawns in codend catches were counted and weighed.

A replicated, paired, controlled study in 2001 of four fished areas of seabed in the Gulf of Carpentaria off Australia (3) found that prawn trawl nets modified with large, supported escape openings (Fisheyes or Bigeyes) or a square mesh escape panel reduced the unwanted catch of sharks *Selachii*, but not rays *Batoidea* or sawfish *Pristidae*, compared to conventional diamond mesh nets. Shark catches were 17% lower in nets modified with either a supported escape opening or a square mesh escape panel (data were combined) compared to conventional nets. There were no differences in catches of rays and sawfish between modified and conventional nets (data reported as statistical results). In addition, when used in combination with any type of size-sorting escape grid, shark and ray catches in modified nets were reduced by 18% and 36%, respectively, compared to conventional nets, but sawfish catches were unaffected. Commercial target prawn *Penaeidae* catch was reduced by 4% in nets modified with one type of large escape opening (Bigeye). Data were collected in August-November 2001 by observers onboard 23 different commercial prawn fishing vessels, from 1,612 deployments (3–4 h) using twin trawls. One trawl net was modified with one of three escape opening/panel designs, with or without size-sorting grids, and was towed with a conventional net on the other side of the trawl (see original paper for gear specifications and numbers of deployments/trawl net type). All catch was identified and counted.

A replicated, randomized, paired, controlled study in 2001 in a fished area of seabed in the Coral Sea off the coast of Queensland, Australia (4) found that a prawn trawl net modified with large, supported escape openings (radial escape section) reduced the overall amount of unwanted catch (fish and invertebrates) compared to a standard net without escape openings. Total unwanted catch (up to 250 fish and invertebrate species combined) was 19% lower in the net with escape openings relative to the average catch rate of the standard net (11 kg/ha). In addition, when used in a net that also had a size-sorting escape grid, the combined system reduced unwanted catch by 24% relative to the standard net catch. Commercial target eastern king prawn *Penaeus plebejus* catches were similar between trawl types (data reported as statistical result). Data were collected from 90 experimental paired trawl deployments at 45 locations on a chartered fishing vessel over ten nights in October 2001. Four codend types were towed in blocks of pairs on either side of a twin trawl: one with a radial escape section only, one with a radial escape section and a size-sorting grid (turtle excluder device), one with a grid only (see paper for data) and one a standard codend. After each deployment unwanted catch was weighed and a subsample frozen and sorted by species in a laboratory.

A replicated, paired, controlled study in 2002 of a fished area of seabed in the Gulf of Carpentaria, off Australia (5) found that using a large, supported escape opening (new design of Fisheye) in a prawn trawl net reduced the amount of unwanted small catch (fish and invertebrates combined) compared to a standard prawn trawl net with no large escape opening. The average catch weight of small unwanted fish and invertebrates was lower with the Fisheye escape opening compared to without (with: 136–219 kg, without: 183–254 kg). In addition, there was no difference in the average catch weights of the commercial target species of tiger prawns, *Penaeus esculentus* and *Penaeus semisulcatus*, between trawl nets (with: 13–18 kg, without: 13–19 kg). Data were collected in November 2002 from 29 comparative trawl deployments by a commercial trawler on prawn fishing grounds in the south-western area of the Gulf. The vessel towed a pair of identical prawn trawl nets, both fitted with a compulsory downward-excluding size-sorting grid (Super-shooter type). One of the trawl nets also had a new design of large escape opening (Yarrow Fisheye): a rigid frame on the upper trawl section, creating a semi-round escape opening (see paper for specifications). The combined use of size-sorting excluder grids with other catch reduction devices was made compulsory in Australia's Northern prawn fishery in 2000. Catches were separated into small unwanted catch (fish and invertebrates combined) and target prawn species and weighed.

A replicated, paired, controlled study in 1997–1999 of two coastal seabed areas in the Atlantic Ocean off Florida, USA (6) found that large, supported escape openings (four designs) fitted to a shrimp roller-frame trawl net reduced the overall unwanted catch of finfish in three of four cases compared to a standard net without escape openings. Across all trials, average catch weights (and numbers, see paper for data) of all non-target finfish were lower in nets with an extended-mesh funnel design of escape opening, both with and without a stimulator cone (funnel: 20–206 g/effort, standard: 53–309 g/effort) and in nets with a Florida Fisheye design and stimulator cone (Fisheye/cone: 107 g/effort, standard: 275 g/effort), compared to standard nets. Total finfish catch rates in nets with just a Florida Fisheye (no stimulator cone) were similar to standard nets (Fisheye/ no cone: 112–230 g/effort, standard: 111–248 g/effort), however, the effect varied between individual fish species (see paper for data). Data were collected from 158 paired trawl deployments targeting pink shrimp *Farfantepenaeus duorarum* in two areas: at Tarpon Springs in October 1997 and March and October 1998 (research vessel), and at Biscayne Bay in November/December 1999 (commercial vessel). One trawl net equipped with one of two escape opening designs (large-mesh extended-mesh funnel or Florida Fisheye), with and without a stimulator cone (nylon webbing designed to prevent finfish from reaching the codend), was towed on one side of each vessel. On the other side a standard net was towed at the same time. Finfish in the catches were sorted by species and weighed.

A replicated study in 2009–2010 of a fished area of seabed in the Pacific Ocean off Oregon, USA (7) found that fish trawl nets fitted with large escape opening systems (two designs) allowed the escape of unwanted Chinook salmon *Onchorynchus tshawytscha* in two of two designs and widow rockfish *Sebastes entomelas* in one of two designs. Results were not tested statistically. In trials of two pairs of escape openings, 80–100% of

Chinook salmon observed to enter the net escaped (escaped: 1–8 fish, entered: 1–11 fish) and 19–33% of rockfish (escaped: 4–8 fish, entered: 21–24 fish). In trials of a single pair of escape openings, 50% of salmon escaped (escaped: 8 fish, entered: 16 fish), but of the 53 rockfish that entered the net, none were observed to escape through the openings. Data were collected in September 2009 and May, August and September 2010 from video footage recorded during 32 trawl deployments (113–259 m depth) on a commercial vessel targeting Pacific hake *Merluccius productus*. Two designs of net were used, with either one (14 h video) or two (17 h video) pairs of large escape openings cut out of the netting on the upper portions of both side panels. Two square mesh ramps in front of the openings acted as a guide to actively swimming fish towards the escape openings (see original paper for gear specifications). A total of 23 tows were done with an open codend, the other nine with a closed codend. Fish entering and escaping through the large openings were identified and counted from the video recordings.

A replicated, paired, controlled study in 2007–2011 in an area of seabed in the Gulf of Mexico, USA (8) found that fitting a large escape opening (nested cylinder design) to a shrimp trawl net reduced the unwanted catch of immature red snapper *Lutjanus campechanus*, compared to a standard net. Across both trials, catch numbers of red snapper were lower in nets with escape openings compared to without (with: 638–877 fish, without: 1,197–1,265). Data were collected from paired trawl deployments carried out on commercial shrimp vessels, in September 2007 off Mississippi (32 deployments) and November 2011 off Texas (32 deployments). One side of a pair of shrimp trawl nets was fitted with a large escape opening design (nested cylinder bycatch reduction device) and the trawl net on other side had no escape opening device (see original paper for gear specifications). Tows were 2–6 hours. Numbers of all immature red snapper caught in each trawl codend were recorded.

(1) Rogers D.R., Rogers B.D., de Silva J.A., Wright V.L. & Watson J.W. (1997) Evaluation of shrimp trawls equipped with bycatch reduction devices in inshore waters of Louisiana. *Fisheries Research*, 33, 55–72.

(2) Brewer D., Rawlinson N., Eayrs S. & Burridge C. (1998) An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. *Fisheries Research*, 36, 195–215.

(3) Brewer D., Heales D., Milton D., Dell Q., Fry G., Venables B. & Jones P. (2006) The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. *Fisheries Research*, 81, 176–188.

(4) Courtney A.J., Tonks M.L., Campbell M.J., Roy D.P., Gaddes S.W., Kyne P.M. & O'Neill M.F. (2006) Quantifying the effects of bycatch reduction devices in Queensland's (Australia) shallow water eastern king prawn (*Penaeus plebejus*) trawl fishery. *Fisheries Research*, 80, 136–147.

(5) Heales D.S, Gregor R., Wakeford J., Wang Y.-G., Yarrow J. & Milton D.A. (2008) Tropical prawn trawl bycatch of fish and seasnakes reduced by Yarrow Fisheye Bycatch Reduction Device. *Fisheries Research*, 89, 76–83.

(6) Crawford C.R., Steele P., McMillen-Jackson A.L. & Bert T.M. (2011) Effectiveness of bycatch-reduction devices in roller-frame trawls used in the Florida shrimp fishery. *Fisheries Research*, 108, 248–257.

(7) Lomeli M.J. & Wakefield W.W. (2012) Efforts to reduce Chinook salmon (*Oncorhynchus tshawytscha*) and rockfish (*Sebastes* spp.) bycatch in the US west coast Pacific hake (*Merluccius productus*) fishery. *Fisheries Research*, 119, 128–132.

(8) Parsons G.R. & Foster D.G. (2015) Reducing bycatch in the United States Gulf of Mexico shrimp trawl fishery with an emphasis on red snapper bycatch reduction. *Fisheries Research*, 167, 210–215.

2.60 Fit mesh escape panels/windows to a trawl net and use square mesh instead of diamond mesh codend

- **One study** examined the effects of fitting mesh escape panels to a trawl net and using a square mesh instead of a diamond mesh codend on marine fish populations. The study was in the English Channel[1] (UK).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Reduction of unwanted catch (1 study):** One replicated, paired, controlled study in the English Channel[1] found that using a trawl net with square mesh escape panels and a square mesh codend reduced the numbers of discarded finfish compared to a diamond mesh codend with no panels.

Background

Mesh escape panels (or windows) in commercial trawl nets are sections of net inserted in the codend or extension piece of a different mesh size and/or orientation (i.e. square) to the rest of the codend. They were developed to provide an area of escape for some fish while retaining target species such as prawns/shrimps that are expected to pass underneath. Square mesh codends provide another area for selection in a trawl net and may allow the escape of smaller fish. Square meshes, as opposed to conventional diamond meshes, are more likely to stay open under tension during trawling and thus create a larger gap through which fish can more easily pass. Thus, the combination of a mesh panel and square mesh codend should allow a larger number and range of individuals to escape from a trawl net than a conventional diamond mesh codend, or one or other of the escape panel or square mesh codend alone. However, likelihood of escape may depend on the species being targeted and the fish assemblages in the area being fished.

The effects of using just mesh panels or just a square mesh codend are summarized under *'Fishing gear modification - Fit mesh panels/windows to a trawl net'* and *'Use a square mesh instead of a diamond mesh codend on trawl nets'*, respectively. Similar interventions of various combinations of unwanted catch reduction devices, including mesh panels and square mesh codends are summarized under *'Fishing gear modification'*.

A replicated, paired, controlled study in 2007 of two fished areas of seabed in the English Channel off southwest England, UK (1) found that beam trawl nets with two square mesh escape panels (top and bottom) and a square mesh codend, reduced discarded fish catch compared to a standard diamond mesh codend with no escape panels. Across both sampling areas, the modified nets with escape panels and square mesh codends caught 54–63% fewer discarded finfish (617–770 fish) than standard diamond mesh codends (1,652–1,685 fish). Total numbers of six of the nine most numerous fish species/groups were reduced in one or both areas by 17–95%, while there were no differences for three species/groups. In addition, modified nets reduced the retained finfish catches in one of two areas by 22% (modified: 558 fish, standard: 718

fish). Catch comparison trials were done at two separate bottom fishing grounds off the south west coast of England by two commercial beam trawl vessels in July and August 2007. A total of 16 deployments were made of two beam trawl nets towed simultaneously: one modified with two 200 mm square mesh panels (upper and lower) and a 80 mm square mesh codend; and a standard 80 mm diamond mesh codend with no square mesh panels (see paper for specifications). Catches from both trawl nets were kept separate and divided into discarded and retained portions. Discarded finfish and all retained fish were identified, and their total lengths measured (sub-sampled where necessary).

(1) Wade O., Revill A.S., Grant A. & Sharp M. (2009) Reducing the discards of finfish and benthic invertebrates of UK beam trawlers. *Fisheries Research*, 97, 140–147.

2.61 Fit a size-sorting escape grid (rigid or flexible) to trawl nets and use a square mesh instead of a diamond mesh codend

- **Three studies** examined the effects of fitting a size-sorting escape grid (rigid or flexible) to trawl nets and using a square mesh instead of a diamond mesh codend on marine fish populations. The studies were in the North Sea[1] (UK), the Kattegat and Skagerrak[2] (Sweden/Denmark) and the Coral Sea[3] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR RESPONSE (0 STUDIES)

OTHER (3 STUDIES)

- **Reduction of unwanted catch (3 studies):** Three replicated, paired, controlled studies (one randomized) in the North Sea[1], Kattegat and Skagerrak[2] and Coral Sea[3] found that trawl nets with an escape grid and a square mesh codend caught fewer unwanted whiting, plaice, cod, haddock[1,2] and unwanted catch of the most frequently caught fish species[3], but not hake[2] or less frequently caught species[3] compared to a diamond mesh codend with no grid. One also found that catch rates of most fish species were similar to a square mesh codend alone[3].

Background

Escape grids are frames of metal, plastics or mesh inserted in or near the codend of trawl nets to try and prevent unwanted species or sizes of catch from entering the codend. They are size selection mechanisms, the sizes at which individuals are sorted dependent on the type of panels and the mesh size and shape. Behaviour of individual fish species may also influence how effective a grid is at allowing escape; some fish will swim upwards in a net whilst others might swim down or to the sides. The effectiveness of escape panels is therefore likely to be dependent on the behaviour, shape, and size of the unwanted fish. Furthermore, constructing the codend using a square shaped mesh instead of a diamond mesh helps to maintain the net's structure under strain, allowing a greater chance for fish to escape through the gaps of the mesh. Combining an escape grid with a square mesh codend may further increase the chance of fish escape for a greater range of species or sizes.

The effects of using just a size-sorting escape grid or just a square mesh codend in trawl nets are summarized under *'Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net'*, *'Fit a size-sorting escape grid (rigid or flexible) to a prawn/shrimp trawl net'* and *'Use a square mesh instead of a diamond mesh codend on trawl nets'*, respectively. Similar interventions of various combinations of unwanted catch reduction devices, including escape grids and square mesh codends are summarized under *'Fishing gear modification'*.

A replicated, paired, controlled study in 2006 of an area of seabed in the North Sea, UK (1) found that prawn trawl nets fitted with a rigid size-sorting escape grid and a square mesh instead of a diamond mesh codend, reduced the catch of all sizes of unwanted whiting *Merlangius merlangus* and the overall amounts of plaice *Pleuronectes platessa*, small cod *Gadus morhua* and small haddock *Melanogrammus aeglefinus*, compared to a standard trawl (no grid, diamond mesh codend). Average catch numbers of whiting of all length groups (11–41 cm) were reduced with a grid and square mesh codend (with: 0–23 fish/tow, without: 5–254 fish/tow). Average catch numbers of plaice, haddock and cod were lower for up to half of the length groups in nets with a grid and square mesh codend (plaice, with: 4–12 fish/tow, without: 1–22 fish/tow; haddock, with: 0 fish/tow, without: 4–52 fish/tow; cod, with: 0–2 fish/tow, without: 4–45 fish/tow). These included the smaller size groups of haddock and cod (see paper for data by length group). In addition, catches of marketable sizes of the target species Norway lobster *Nephrops norvegicus* were reduced in trawls with a grid and square mesh codend (with: 0.8–0.9, without: 1.2–2.0 baskets/trawl) but discards were also lower (with: 0.5, without: 2.4 baskets/trawl). In March 2006, a total of 10 paired deployments were made by a twin-rig vessel in the Farn Deeps *Nephrops* fishing ground off the coast of England. The vessel towed two trawl nets simultaneously: one 80 mm *Nephrops* trawl fitted with a metal grid (Swedish grid) and a 70 mm square mesh codend; and one standard 80 mm *Nephrops* trawl net with a 85 mm diamond mesh codend.

A replicated, paired, controlled study in 2002–2006 of two seabed areas in the Skagerrak and Kattegat off Sweden/Denmark (2) found that prawn trawl nets fitted with size-sorting escape grids (two types) and a square mesh instead of a diamond mesh codend, reduced the discarded catches of four of five fish species compared to a standard trawl net with no grid and a diamond mesh codend. Average discarded catch rates of cod *Gadus morhua,* whiting *Merlangius merlangus*, haddock *Melanogrammus aeglefinus* and plaice *Pleuronectes platessa* were lower in trawl nets with a grid and square mesh codend for two of two grids (all species, with: 0.4–18.8 kg/tow, without: 2.5–67.4 kg/tow), and hake *Merluccius merluccius* was lower for the flatfish grid (with: 3.3 kg/tow, without: 9.3 kg/tow), and similar for the Nordmøre grid (with: 0.0 kg/tow, without: 0.3 kg/tow). In addition, the weight of undersized and marketable target catch of *Nephrops norvegicus* was lower for one of two grids (flatfish grid) and similar for the other. Data were collected from two trials on commercial *Nephrops* fishing grounds in Skagerrak/Kattegat in November 2002 and June 2006. A total of 17 paired deployments were made by two twin-rig vessels towing two nets simultaneously: one net fitted with either a 35 mm rigid grid (Nordmøre) or a 'flatfish' grid (horizontal bars) and a 70 mm square mesh codend, and one net with either a 70 or 90 mm diamond mesh codend (see paper for gear specifications). All catches were sorted and weighed.

A replicated, randomized, paired, controlled study in 2002 of a coastal seabed site in the Coral Sea, Australia (3) found that prawn trawl nets fitted with a size-sorting escape grid (a turtle excluder device) and a square mesh codend reduced the catches of the most frequently caught unwanted fish species, but not of less frequently caught species compared to a standard diamond mesh codend, and overall fish catch rates were similar to a square mesh codend alone. For seven of eight unwanted fish species caught in 26–85% of tows, average catch rates were lower in nets with a grid and square mesh codend (with: 0–93 g/ha, standard: 6–134 g/ha) and were similar for one species (with: 7 g/ha, standard: 5 g/ha). For a further 18 unwanted fish species caught in 6–31% of tows, there were no differences in average catch rates between grid/square mesh codend nets and standard nets (with: 0–43 g/ha, without: 1–27 g/ha). In addition, the catch rates of most unwanted fish (24 of 26 species) were similar to a square mesh codend without a grid (see paper for individual data). Catch rates of the target eastern king prawns *Melicertus plebejus* were similar between all net types (grid/square mesh codend: 264, square mesh codend: 267, standard: 274 g/ha). In July 2002, data were collected from 65 paired trawl deployments done over 10 nights off the coast of Queensland. Three different codends were tested against a standard diamond mesh codend: a standard diamond mesh with a metal, top-opening grid (Wick's turtle excluder device), the grid in combination with a square mesh codend, and a square mesh codend alone (see paper for specifications). Each codend design was randomly assigned to the two trawl nets every 12 tows. Each tow was 2 nm long, at 2.2 knots.

(1) Catchpole T.L., Revill A.S. & Dunlin G. (2006) An assessment of the Swedish grid and square-mesh codend in the English (Farn Deeps) *Nephrops* fishery. *Fisheries Research*, 81, 118–125.

(2) Valentinsson D. & Ulmestrand M. (2008) Species-selective *Nephrops* trawling: Swedish grid experiments. *Fisheries Research,* 90, 109–117.

(3) Courtney A.J., Campbell M.J., Tonks M.L., Roy D.P., Gaddes S.W., Haddy J.A., Kyne P.M., Mayer G.G. & Chilcott K.E. (2014) Effects of bycatch reduction devices in Queensland's (Australia) deepwater eastern king prawn (*Melicertus plebejus*) trawl fishery. *Fisheries Research*, 157, 113–123.

2.62 Fit a size-sorting escape grid (rigid or flexible) and large, supported escape openings to trawl nets

- **Four studies** examined the effect of fitting trawl nets with a size-sorting escape grid and large, supported escape openings for fish escape on marine fish populations. Two studies were in the Gulf of Carpentaria[1,2] (Australia), one study was in the Atlantic Ocean[3] (USA) and one study was in the Persian Gulf[4] (Iran).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (4 STUDIES)

- **Reduction of unwanted catch (4 studies):** Three of four replicated studies (three paired and controlled) in the Gulf of Carpentaria[1,2], the Atlantic Ocean[3] and the Persian Gulf[4], found that trawl nets fitted with a both a size-sorting escape grid and a large, supported escape opening reduced the catches of unwanted fish[1,4] and sharks and rays[2], but not sawfish[2], compared to standard trawl nets. The other study[3] found that trawl nets with an escape grid/opening caught similar amounts of unwanted sharks to trawl nets without.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Trawl nets may be fitted with devices that aim to enable unwanted catch to escape ("bycatch reduction devices"). A wide variety of different devices have been developed, including size-sorting escape grids and supported openings, each designed to allow specific species or sizes to escape while at the same time minimising losses of marketable catch. Fitting escape grids in combination with a large, supported opening should increase the likelihood of fish escape by providing fish (potentially of different species or sizes) with an additional opportunity to make contact with one or other of the devices.

Evidence for the individual effects of size-sorting escape grids and large, supported escape openings in trawl nets is summarized under '*Fishing gear modification - Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net*', '*Fit a size-sorting grid (rigid or flexible) to prawn/shrimp trawl nets*', and '*Fit large, supported escape openings (such as Fisheyes, Bigeyes and radial escape sections) to trawl nets*'. Similar interventions of various combinations of unwanted catch reduction devices, including escape grids, are summarized under '*Fishing gear modification*'.

A replicated, paired, controlled study in 1995 of an area of seabed in the Gulf of Carpentaria, Australia (1) found that prawn trawl nets fitted with rigid size-sorting escape grids (two designs) in combination with either a large, supported escape opening (Fisheye) or a square mesh escape window, caught fewer unwanted fish compared to an unmodified conventional trawl. Data were reported as percentage reductions. The weight of unwanted fish caught in experimental trials of the modified nets was lower than conventional trawls: by 14–16% with a combined Super Shooter grid and Fisheye escape opening, by 28–31% with a Nordmøre grid and a Fisheye, and by 29–39% with a Nordmøre grid and a square mesh window. The Super Shooter/Fisheye system caught similar weights of commercial target prawns *Penaeidae* relative to conventional trawls (91–95%), while both Nordmøre systems caught less (Nordmøre/Fisheye: 14–18%, Nordmøre/square mesh: 17–34%). Standard prawn trawl nets were fitted with a combination of catch reduction devices: one of two size-sorting escape grids ('Super Shooter' or 'Nordmøre') and either a single large escape opening ('Fisheye') or a square mesh escape window in the codend. Paired trawl deployments, each with a different modified trawl, were conducted in experimental trials in October 1995 (146 paired tows, length 120 min). Full details of the gear designs are provided in the original study.

A replicated, paired, controlled study in 2001 of bottom fishing grounds in the Gulf of Carpentaria, Australia (2) found that prawn trawl nets fitted with a large, supported opening (a 'Bigeye') and a size-sorting escape grid reduced the catch of unwanted sharks and rays *Batoidea*, but not sawfish *Pristidae*, compared to a conventional diamond mesh trawl net. Shark catches were reduced by 18% and ray catches by 36% in trawls with a 'Bigeye' opening in combination with an excluder grid, compared to a conventional trawl. There was no statistical difference in overall catch of sawfish between gear types (grid/Bigeye: 17 fish, conventional: 32 fish). Trawl nets with a Bigeye/grid reduced commercial target prawn *Penaidae* catches by 6% compared to the conventional trawl. In

August-November 2001, data were collected from 23 prawn fishing vessels towing twin trawls, one modified and one conventional, with a total of 1,612 tows for 3–4 hours each, on either side of the vessel. Modified trawls were fitted with an upward-angled grid with an escape outlet plus a 'Bigeye' escape opening nearer to the codend and were paired with a conventional trawl used by the prawn fishery. See original study for full escape panel specifications. All catch was identified, weighed, and counted.

A replicated study in 1995–1998 of seabed sites in the Atlantic Ocean off the coast of Georgia, USA (3) found that the amount of unwanted sharks (Selachii) caught by commercial shrimp trawl nets did not differ between those fitted with both a large, supported opening and rigid size-sorting escape grid compared to just a grid. Average shark catch rates in mongoose nets (most commonly used commercially) fitted with 'Super Shooter' grids were similar with and without a 'Fisheye' escape opening in the codend (with: 15 sharks net/h, without: 17 sharks net/h). In addition, compared to other trawl/grid types without Fisheyes, shark catch rate with the mongoose/Super Shooter/Fisheye combination was not significantly different (mongoose/Georgia Jumper: 2, flat net/Super Shooter: 2, triple wing net/Super Shooter: 23 sharks/net/h). In April 1995–January 1998 (except February and March), data were collected by fishery observers from 30 trawl deployments using mongoose, flat and triple wing nets, carried out by commercial vessels fishing for shrimp. All nets had a size-sorting escape grid (Super Shooter or Georgia Jumper). Nine mongoose net deployments were made with the supported escape opening (Fisheye) and eight without. See original paper for further gear descriptions.

A replicated, paired, controlled study in 2013 of shallow, coastal waters in the Persian Gulf off Iran (4) found that shrimp trawl nets fitted with one of two experimental rigid sorting grids (Nafted or Nordmøre) and either with or without a large, supported escape opening (Fisheye) caught fewer small, unwanted fish compared to a standard trawl without a grid or opening. The Nafted/Fisheye trawl net caught 53% fewer narrow-barred Spanish mackerel *Scomberomorous commerson*, 45% fewer tigertooth croaker *Otolithes ruber* and 55% fewer silver pomfret *Pampus argenteus* than the standard trawl. The trawl with the Nordmøre grid alone caught 59% fewer mackerel, 45% fewer croaker and 55% fewer pomfret than the standard trawl. In total, 15 trawl deployments with each grid type were conducted from a commercial fishing vessel in 2013 in depths of 13–33 m. Tows were 1.5 h long at speeds of 2.5–3 knots. Trawls were double rigged and towed an experimental net alongside a standard net. Both grid types were inclined at 45° with 60 mm bar spacing. The Nafted grid had a Fisheye steel frame sewn into the top of the codend for fish to escape (see paper for gear specifications).

(1) Brewer D., Rawlinson N., Eayrs S. & Burridge C. (1998) An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. *Fisheries Research*, 36, 195–215.

(2) Brewer D., Heales D., Milton D., Dell Q., Fry G., Venables B. & Jones P. (2006) The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. *Fisheries Research*, 81, 176–188.

(3) Belcher C.N. & Jennings C.A. (2011) Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management. *Fisheries Management and Ecology*, 18, 104–112.

(4) Paighambari S.Y. & Eighani M. (2016) Size selection of three commercial fish using sorting grids in the Persian Gulf shrimp trawl fishery. *Regional Studies in Marine Science*, 3, 251–253.

2.63 Fit mesh escape panels/windows and a size-sorting grid (rigid or flexible) to a trawl net

- **Six studies** examined the effects of fitting trawl nets with mesh escape panels or windows and a size-sorting grid on marine fish populations. Two studies were in the Atlantic Ocean[3,5] (Portugal, Suriname), two were in the Indian Ocean[2,4] (Australia, Mozambique), one study was in the Gulf of Carpentaria[1] (Australia) and one was in the English Channel[6] (UK).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (6 STUDIES)

- **Reduce unwanted catch (5 studies):** Four of five replicated studies (four paired, controlled) in the Gulf of Carpentaria[1], Indian Ocean[2,4] and Atlantic Ocean[3,5], found that bottom trawl nets fitted with square mesh escape panels and size-sorting grids of various types reduced the unwanted catch (non-target or undersized) of fish[1,3], sharks and stingrays[1], rays[5] and total discarded catch (fish and invertebrates)[4], compared to standard unmodified trawl nets, and that fish escape through either the panel/window, grid, or both varied between fish species[3] or sizes[5]. The other study[2] found that the escape of non-target fish from the combined use of a square mesh panel and grid depended on the position of the panel in the net.
- **Improved size-selectivity of fishing gear (1 study):** One replicated, paired, controlled study in the English Channel[6] found that size-selectivity of whiting was increased in bottom trawl nets fitted with square mesh escape panels or cylinders in combination with one or two size-sorting grids of different types, compared to standard nets.

Background

Trawling is a method of fishing that involves pulling a fishing net (trawl) through the water behind one or more vessels. Trawls may be fitted with devices to allow unwanted catch to escape (often termed "bycatch reduction devices"). A variety of unwanted catch reduction devices have been developed aiming to enable specific sizes or groups of unwanted fish to escape the trawl net. These include rigid or flexible size-sorting or excluder grids, and also large square-, or diamond-mesh panels, fitted into the codend of a trawl net (Sinclair & Valdimarsson 2003). Positioning of both types of devices as well as opening size, mesh size or bar spacing and orientation can affect the type and sizes at which fish can escape.

Evidence for the individual effects of mesh escape panels/windows and size-sorting escape grids in trawl nets is summarized under '*Fishing gear modification - Fit mesh escape panels/windows to a trawl net*', '*Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net*' and '*Fit a size-sorting grid (rigid or flexible) to prawn/shrimp trawl nets*'. Similar interventions of various combinations of unwanted catch reduction devices, including mesh panels/windows and escape grids, are summarized under '*Fishing gear modification*'.

Valdemarsen J.W., Suuronen P. 2003. Modifying Fishing Gear to Achieve Ecosystem Objectives. *In* Responsible Fisheries in the Marine Ecosystem. Food and Agriculture Organisation of the United States & CABI Publishing, 426 pp.

A replicated, paired, controlled study in 1995–1996 of two fished areas of seabed in the Gulf of Carpentaria, Australia (1) found that prawn trawl nets fitted with a square mesh escape panel in combination with a rigid size-sorting grid caught fewer unwanted fish, sharks and stingrays (Elasmobranchii) compared to an unmodified conventional trawl net. In the first of two trials, catch weights of unwanted fish in nets with a square mesh window and a rigid grid (Nordmøre) were reduced by 29–39% relative to a conventional net. In the second trial (commercial conditions), a square mesh window and grid (Super Shooter) caught fewer sharks (3) and stingrays (0) compared to a conventional trawl net (sharks: 12, stingrays: 2). Shark and stingray data were not tested statistically. In addition, target prawn *Penaeidae* catches were reduced by 17–34% in the square mesh window/Nordmøre system and average catch weight decreased from 41 kg in conventional nets to 38 kg in the square mesh window/Super Shooter system. Catch data were collected from deployments of two modifications of a standard prawn trawl net with a diamond mesh codend, each with a square mesh escape window grid fitted behind a rigid size-sorting grid (Nordmøre or Super Shooter) (see original paper for gear specifications). The modified nets were towed in paired deployments with other modified net designs and/or standard unmodified nets in Australia's Northern Prawn Fishery area; during experimental trials in October 1995 (73 paired tows, 2h duration) and in commercial trials in October 1996 (24 paired tows, 2–3 h duration).

A replicated, paired, controlled study in 2000 in an area of soft seabed in the Indian Ocean, off Western Australia (2) found that the effect of prawn trawl nets fitted with square mesh escape panels and rigid grids on non-target fish catch compared to a standard net, varied with the position of the escape panel. Compared to a standard net, trawl nets with the square mesh panel located in the rear section of the codend further away from the grid, reduced the non-target catches of two of seven non-commercial, and two of three commercial fish species, by between 50–76% in number and 47–73% by weight (see original paper for species individual data). Catches of the five other species were similar between the nets. No differences in non-target catches of the 10 fish species were found between the net with a grid and panel located forward of the codend (nearer the grid) and the standard net (see original paper for species individual data). In addition, the total catch weights of the target prawns *Penaeidae* were reduced in both grid/panel nets, by 12–14%. In August 2000, two sets of 10 paired trawl deployments (40 min each) were done in Shark Bay using one of two designs of modified trawl and a standard trawl net (47 mm diamond mesh, no grid or panel) simultaneously. The modified trawl nets were standard nets fitted with a Nordmøre rigid grid (100 mm bar spacing) located in front of the codend, and a square mesh escape panel (47, 94 and 155 mm mesh sections) at either the rear or front section of the codend (see original paper for gear specifications). All catch was sorted, counted, and weighed.

A replicated study in 2003 of an area of seabed in the Atlantic Ocean off Portugal (3) found that bottom trawl nets fitted with a square mesh escape window in addition to a rigid size-sorting escape grid, enabled the escape of high proportions of undersized commercially targeted and non-target fish species, and the main means of escape (window or grid) varied between bottom and mid-water dwelling species. Data were not statistically tested. The proportion (by number) of individuals of commercially targeted fish below their respective minimum landing sizes that escaped was 62–79% (grid) and 8–15% (square mesh window) for two bottom dwelling species; and 0–14% (grid) and 60–100% (window) for two pelagic commercial species. For non-target species, the percentage (by weight) of escaped individuals of one bottom dwelling species was 48%

(grid) and 1% (window), and for two pelagic species the grid excluded 13–17% and the window 17–72%. In September 2003, a total of 26 trawl net deployments were done by research vessel off the north west coast of Portugal at 40–150 m depth. Trawl nets were fitted with either a Nordmøre grid (plastic, 1.5 × 1 m, 30 mm bar spacing) on its own (17 hauls), or a Nordmøre grid and a square mesh window (1.8 m long, 50 mm mesh size) inserted just behind the top section of the grid (9 hauls). A 'flapper' net guided catch to the bottom of the grid, the upper 40 cm of which had no bars to allow retained catch to pass into the codend, while catch that passed through the grid (excluded) was retained by an inner net. A cover attached over the square mesh window collected fish escaping through the meshes of the window (see original paper for gear specifications). Fish collected in the codend, inner net and cover were sampled.

A replicated, paired, controlled study in 2005 of an area of seabed in the Indian Ocean, off Mozambique (4) found that a prawn trawl net with a square mesh escape window and a size-sorting escape grid reduced the overall discarded catch (fish and invertebrates) compared to a conventional trawl net. Average catch rates of discards (90% fish, 10% invertebrates) were lower in the net with a square mesh panel and size-sorting grid (30 kg/h) compared to a conventional trawl net without a panel or grid (56 kg/h). In addition, average catch rates were also reduced by a square mesh panel (panel: 37 kg/h, conventional: 50 kg/h), or grid (grid: 36 kg/h, conventional: 52 kg/h) alone, compared to a conventional trawl without either. Catch rates of retained fish were similar between nets (panel/grid: 4 kg/h, conventional: 5 kg/h), and the catch of targeted prawn (mostly *Fenneropenaeus indicus*) was lower in a panel/grid net (panel/grid: 6 kg/h, conventional: 8 kg/h). Data was collected in February 2005, from a total of 23 trawl deployments (6–21 m) using a twin-rigged trawler towing a test net and a conventional diamond mesh trawl net side by side. Test nets were the conventional design fitted with either: a square mesh escape panel (143 mm mesh size) and a rigid grid ('Nordmøre', 100 mm bar spacing) (eight deployments); a square mesh panel alone (11 deployments); or a grid alone (four deployments). See original paper for gear specifications.

A replicated, paired, controlled study in 2012–2013 in a fished area of seabed in the Atlantic Ocean, off Suriname (5) found that a shrimp trawl net fitted with a square mesh escape panel in combination with a size-sorting escape grid reduced the overall catch of rays and individuals of three of five ray species, compared to a standard commercial trawl net, but larger rays had higher escape rates than smaller rays. Overall ray catch rate was reduced by 36% in nets with a panel and grid compared to without. By species, between 32–77% fewer individuals of sharpsnout stingray *Dasyatis geijskesi* (panel/grid: 38, without: 161 ind), longnose stingray *Dasyatis guttata* (panel/grid: 440, without: 741 ind) and smooth butterfly ray *Gymnura micrura* (panel/grid: 572, without: 858 ind) were caught, and catches were similar between trawl types for cownose ray *Rhinoptera bonasus* (panel/grid: 8, without: 11 ind) and smalleyed round stingray *Urotrygon microphthalmum* (panel/grid: 171, without: 181 ind). Rays caught in the panel/grid net were on average 21% smaller than rays caught in the standard net (panel/grid: 26 cm, without: 32 cm), significantly smaller for sharpsnout (38%) and longnose stingrays (23%), and catch rate of all species combined declined with increasing size in the panel/grid net (data reported graphically). Trials were done on Atlantic seabob shrimp *Xiphopenaeus kroyeri* fishing grounds during eight commercial trips from February 2012 to April 2013. A total of 65 simultaneous deployments of a standard diamond mesh trawl net (45 mm mesh size codend) fitted with a square mesh panel (150 mm mesh size) and a grid (aluminium 'Super Shooter' turtle excluder device, 10 cm bar spacing), and a standard trawl net were completed (2.5–3.5 knots, 1 h). All rays caught were identified, counted and wing width recorded. See original paper for gear specifications.

A replicated, paired, controlled study in 2010–2013 of a seabed area in the English Channel, UK (6) found that bottom trawl nets fitted with square mesh escape panels or cylinders in combination with a sorting grid(s) of different designs, increased the size-selectivity of whiting *Merlangius merlangus* compared to a standard trawl net. Overall, both nets tested improved the escape of whiting under 30 cm in length (minimum landing size 27 cm) compared to a standard net. A square mesh panel with two consecutive flexible grids allowed whiting of all lengths to escape, while a square mesh cylinder with one rigid grid allowed significant escape of whiting up to 31 cm length. Data were reported as statistical model results and catch probability curves. Trials were done in June 2010 and November 2013 by commercial trawlers fishing parallel to each other: one rigged with a modified net and the other a standard net. In the first trial, a net fitted with a square mesh panel and two flexible grids of different designs was tested (18 paired deployments). In the second trial, a net fitted with a square mesh cylinder around the entire section circumference and an aluminium grid (30 mm spaced vertical bars) was tested (21 paired deployments) (see original paper for gear specifications). Fish length and weight in catches were recorded. Random sub-sampling was done when catches were large.

(1) Brewer D., Rawlinson N., Eayrs S. & Burridge C. (1998) An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. *Fisheries Research*, 36, 195–215.

(2) Broadhurst M.K., Kangas M.I., Damiano C., Bickford S.A. & Kennelly S.J. (2002) Using composite square-mesh panels and the Nordmøre-grid to reduce bycatch in the Shark Bay prawn-trawl fishery, Western Australia. *Fisheries Research*, 58, 349–365.

(3) Fonseca P., Campos A., Mendes B. & Larsen R.B. (2005) Potential use of a Nordmøre grid for by-catch reduction in a Portuguese bottom-trawl multispecies fishery. *Fisheries Research*, 73, 49–66.

(4) Fennessy S.T. & Isaksen B. (2007) Can bycatch reduction devices be implemented successfully on prawn trawlers in the Western Indian Ocean? *African Journal of Marine Science*, 37, 421–426.

(5) Willems T., Depestele J., De Backer A. & Hostens K. (2016) Ray bycatch in a tropical shrimp fishery: Do Bycatch Reduction Devices and Turtle Excluder Devices effectively exclude rays? *Fisheries Research*, 175, 35–42.

(6) Vogel C., Kopp D., Morandeau F. Morfin M. & Mehault S. (2017) Improving gear selectivity of whiting (*Merlangius merlangus*) on board French demersal trawlers in the English Channel and North Sea. *Fisheries Research*, 193, 207–216.

2.64 Use a different design or configuration of size-sorting escape grid/system in trawl fishing gear (bottom and mid-water)

- **Twenty-three studies** examined the effects of using a different design or configuration of size-sorting escape grid/system in trawl fishing gear on marine fish populations. Ten studies were in the Atlantic Ocean[1,5,9,11,12,13,14,15,16,22] (Canada, USA, Brazil, Spain, Norway). Five studies were in the Barents and/or Norwegian Sea[7,17,18,19,23] (Norway). Two studies were in the Kattegat and Skagerrak[8,20] (Denmark/Sweden). One study was in each of the Arafura Sea[2] (Australia), the Greenland Sea[3] (Norway), the North Sea[4] (Norway), the North Pacific Ocean[10] (USA) and the Indian Ocean[21] (Australia). One study was in a laboratory[6] (Japan).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

OTHER (23 STUDIES)

- **Reduction of unwanted catch (17 studies):** Six of 16 replicated studies (eight paired and controlled, three controlled, one randomized and controlled, and one paired) in the Atlantic Ocean[1,5,9,11,12,13,14,15], a laboratory[6], Arafura Sea[2], Barents Sea[19], Kattegat and Skagerrak[8,20], Greenland Sea[3], North Sea[4], Pacific Ocean[10] and the Indian Ocean[21], and one controlled study in the Barents Sea[23] found that using a different design or configuration of size-sorting escape grid/system in trawl nets reduced the unwanted (undersized, non-target, discarded) catches of all or most of the fish species assessed[2,3,4,10,11,15,23], compared to standard or other grid designs/configurations. Four studies[6,9,20,21] found that the effect of using different escape grids on the reduction of unwanted catch varied with fish species[20,21], light conditions[6], and the type of trawl net used[9]. The other six[1,5,8,12,13,14] found that, overall, using a different escape grid did not reduce unwanted fish catch.
- **Improve size-selectivity of fishing gear (7 studies):** Three of seven replicated studies (three controlled, one paired and controlled) in the Barents/Norwegian Sea[7,17,18,19], the Atlantic Ocean[16,22] and the Greenland Sea[3] found that different types or configurations of size-sorting escape grid systems in trawl nets resulted in better size-selectivity for unwanted redfish[16] and Greenland halibut[17] and of commercial target hake[22] compared to other designs or configurations. Three studies[3,7,19] found that the effect of using a different design or configuration of size-sorting escape grid/system on improving the size-selectivity of trawls varied between fish species compared to standard or other escape grid designs. The other[18] found that a new design of grid system did not improve the size-selectivity of unwanted redfish compared to an existing system.

Background

In some trawl fisheries, the commercially targeted species are small (e.g. shrimp and prawn fisheries, but also fisheries for mixed fish species) and so the nets have small mesh sizes to help prevent commercial catch from passing through them and escaping. Whilst this might be effective for retaining target catch, unwanted species or sizes of fish are also unable to escape. To minimise the amount of unwanted catch, a grid device (an excluder or size-sorting grid) can be fitted to a trawl net that helps to stop unwanted fish from entering the codend (He & Balzano 2007, Sistiaga *et al.* 2011). However, the effectiveness of grids in any given fishery may largely depend on the body shape as well as size of the unwanted species and/or their escape behaviour (i.e. whether they tend to swim up or down to avoid the net). Using a different design or configuration of escape grid or system (such as two grids) may help to further reduce unwanted catch by tailoring the modifications to suit specific species or sizes of unwanted fish, for example if having horizontal or vertical grid bars, or two grids instead of one, increase the likelihood of escape.

Evidence for related interventions is summarized under '*Fishing gear modification – Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net*' and '*Fit a size-sorting escape grid (rigid or flexible) to a fish trawl net*'. Similar interventions of various combinations of unwanted catch reduction devices, including escape grids, are summarized under *'Fishing gear modification'*.

He P. & Balzano V. (2007) Reducing the catch of small shrimps in the Gulf of Maine pink shrimp fishery with a size-sorting grid device. *ICES Journal of Marine Science*, 64, 1551–1557.

Sistiaga M., Herrmann B., Nielsen K.N. & Larsen R. B. (2011) Understanding limits to cod and haddock separation using size selectivity in a multispecies trawl fishery: An application of FISHSELECT. *Canadian Journal of Fisheries and Aquatic Science*, 68, 927–940.

A replicated, controlled study in 1992–1993 of three fished areas of seabed on the Scotian Shelf, Atlantic Ocean, Canada (1) reported that changing the configuration of size-sorting escape grids (grid angle, bar orientation and increased spacing, guiding device) in small-mesh fish trawl nets did not appear to improve the overall escape of unwanted saithe *Pollachius virens* and haddock *Melanogrammus aeglefinus*, compared to a standard grid configuration. Data were not tested statistically. Percentage escapement (by weight) of saithe in modified grid configurations ranged between 43–92%, and for the standard grid escapement was 95–98%. For haddock, escapement in modified grid configurations was 62–100%, and with the standard grid it was 85–94%. In addition, escapement of the commercial target species, silver hake *Merluccius bilinearis*, was 1–43% with modified grid configurations and 2–5% with the standard grid. Data were collected from three experimental fishing trials on one research vessel and two commercial vessels in June 1992 and May and June 1993. Grids modified with different bar spacings (40 and 50 mm), angles (25° and 45–50°), bar type (vertical or horizontal) and guiding devices (with panel/funnel or without) were tested against a 'standard' grid of 40 mm vertical bar spacing, installed at 45–60° angle and with a guiding funnel in front of it (see paper for full specifications). A second (top) codend was attached over the escape opening above the grid to collect the fish escaping from it. A total of 81 deployments (1-3 h duration) were made.

A replicated, paired, controlled study in 2001 of bottom fishing grounds in the Arafura Sea, Australia (2) found that using a different configuration and type of size-sorting escape grid (upward or downward opening) in prawn trawl nets increased the escape rate of unwanted sharks *Selachii* and to a lesser extent rays *Batoidea*, but not sawfish *Pristidae*, compared to trawl nets with no grid. For sharks, catches were reduced by 20% with upward-excluding grids compared to no grid and were more effective than downward-excluding grids that reduced catches by 9% compared to no grid. For rays the opposite effect was found with catches reduced by slightly more from a downward-excluding grid (35%) than an upward-excluding grid (27%) compared to no grid. No grid system reduced catches of sawfish. Data comparing grid types was not tested statistically. Data were collected from up to 1,612 paired trawl comparisons (3,224 nets sampled over 442 nights of trawling) from 23 different vessels in August-November 2001, in the Gulf of Carpentaria, testing a range of catch reduction devices were tested. Nets with and without escape grids (varied designs) were towed simultaneously from one randomly assigned side of each vessel. Escape grid designs included 14 downward-excluding grids and nine upward-excluding grids, made either of stainless steel or aluminium and with or without guiding panels/funnels (see paper for specifications). All codend catches were sorted and identified by species, weighed and counted.

A replicated, controlled study in 2004 of an area of seabed in the Greenland Sea, Norway (3) found that changing the configuration (lowering the angle of installation) of a size-sorting escape grid in a shrimp trawl net reduced the capture of unwanted small fish, and improved the size-selectivity of haddock *Melanogramus aeglefinus* and Greenland halibut *Reinhardtius hippoglossoides*, but not cod *Gadus morhua*, compared to higher grid angles. Lowering the grid installation angle to 33° from an initial 36° increased the average escapement rate of unwanted fish (lower: 82%, initial: 67%), and a higher angle (39°) allowed an average escape of 73% of fish (data not statistically tested). The average length at which fish had a 50% chance of escape was greater with the lowered grid angle compared to the highest for haddock (lowest: 18.5 highest: 15.0 cm) and halibut (lowest: 22.6 highest: 20.9 cm), but similar between angles for cod (lowest: 17.3 cm, highest: 17.1). In addition, catches of the target species northern shrimp *Pandalus borealis* were reduced by 8% at the lowest grid angle, and by 4–6% at the intermediate and highest angles. Fishing trials took place in the Ice Fjord and Minke Bank (240–415 m depth), off Svalbard, from a research trawler in November–December 2004. Data were collected from 25 trawl deployments using a modified Nordmøre grid with tear-drop shaped bars instead of circular ('Cosmos' grid, 19 mm bar spacing), installed at three different angles: lowered (33.5°, 16 hauls), intermediate (36.8°, 5 hauls) and increased (38.1°, 5 hauls). A cover installed over the grid collected the escaping catch. See original paper for gear specifications.

A replicated study in 1997–1999 of a seabed area in the North Sea off Norway (4) found that using a different configuration of size-sorting escape grid (decreased bar spacing and bar thickness) in fish trawl nets increased the escape of larger individuals of unwanted haddock *Melanogrammus aeglefinus* in an industrial trawl fishery for Norway pout *Trisopterus esmarkii*. In the 1997 trials, the average percentage of non-target haddock that was sorted out by the grids (i.e. too large to pass through the grid into the codend) increased with decreasing bar spacing (19 mm: 77%, 22mm: 41%, 25 mm: 34%. However, the sorted-out haddock (all grids) were of larger lengths than those retained in the codends (data reported as cumulative length frequencies). In separate trials in 1998–1999, the length at which haddock had a 50% chance of not passing through the grid into the codend was smaller with a thinner 5 mm bar thickness of grid (18 cm) than either a 10 mm or 15 mm grid (both 19.4 cm). This was found to indicate that more larger individuals were able to escape from the grid with the bar spacing that had the highest flow of water (as determined separately in flume tank tests). Data were collected from three trials on two vessels in June 1997, May 1998 and September/October 1999 using trawl nets fitted with 1.4 × 1.9 grids and top escape opening. Trials in 1997 used grids of 19 mm, 22 mm and 25 mm bar spacing. The 22 mm grid only was used in 1998 and 1999 for grids with either 5 mm, 10 mm or 15 mm bar thickness. A small mesh cover over the escape opening collected the catch escaping via each grid.

A replicated, paired, controlled study in 2006 of a bottom fishery in the Gulf of Maine, Atlantic Ocean, USA (5) found that using a different configuration of size-sorting escape grid (two grids) in a shrimp trawl net did not typically reduce the capture of unwanted fish compared to a conventional net with just one grid. In two of two trials (with and without guiding funnels), average catch rates of four of five unwanted fish species (whiting *Merluccius bilinearis*, long rough dab *Hippoglossoides platessoides*, redfish *Sebastes* spp., and red hake *Urophycis chuss*) were similar between two-grid and single grid nets (two: 4–120 fish/h, single: 5–129 fish/h). For the other species, witch flounder (*Glyptocephalus cynoglossus*, catch rate was similar between grid nets when no guiding funnel was used (two: 20 fish/h, single: 21 fish/h), but lower in the two-grid system when it was used (two: 27 fish/h, single: 51 fish/h). In addition, average size of the target commercial species Northern shrimp *Pandalus borealis* was larger for both designs of the two-grid nets compared with the single grid (two: 21.4–21.8 mm, single: 20.0–21.2 mm). Between March and June 2006, data were collected from 11 (two grid/no funnel) and 14 (two grid/with funnel) paired deployments by inshore trawlers of nets fitted with secondary grid systems and standard nets with one grid alone. Two-grid nets were fitted with a standard grid design (Nordmøre, 25 mm bar spacing, top opening for fish escape), plus a smaller shrimp size-sorting grid (11 mm bar spacing, bottom opening to allow small shrimp escape), and either a guiding funnel or no funnel. Control nets were fitted with a Nordmøre grid alone and a funnel (see original paper for specifications). Numbers, weights and sizes of individuals of the main non-target fish species and the target shrimp species were recorded.

A replicated study (year not stated) in a laboratory in Japan (6) reported that changing the configuration of a size-sorting escape grid (orientation) allowed more small masu salmon *Oncorhynchus masou* to escape in the dark but not in the light, under simulated trawling conditions. Results were not statistically tested. In dark conditions, the proportion of salmon that escaped through the grids was 67–87% for a backward sloping grid, 60% for a forward sloping grid and 47–53% for a flat/parallel grid. In the light, 100% of salmon escaped through each of the backward and forward sloping grids, and 87–100% escaped with the flat grid. Six trials were conducted (sampling date/year unspecified) using three grid orientations at each of two towing speeds (1 and 1.5 knots); three in dark and three in light conditions. For each trial, five juvenile salmon (12–14 cm length) were released into a circular canal 75 cm wide and 50 cm deep and forced to swim inside a framed net driven around the canal by a motor, to simulate a trawl deployment. The rigid sorting grid (38 mm bar spacing) was fixed to the bottom net frame at three orientations: flat, forward facing or backward facing. Fish were forced to swim for a maximum of 30 min and escapes were monitored by video camera.

A replicated, paired, controlled study in 2006–2007 of a fished area of seabed in the Barents Sea off the coast of Troms and Finnmark, northern Norway (7) found that using a different configuration of size-sorting escape grid (increased bar spacing) in a bottom fish trawl improved the size-selectivity of cod *Gadus morhua* but not haddock *Melanogrammus aeglefinus*. For cod, the average length at which fish had a 50% chance of escape was greater between the two highest bar spacings compared to the two smallest bar spacings, with no other differences (80 mm: 73 cm, 70 cm: 65 cm, 60 mm: 58 cm, 55 mm: 56 cm). For haddock, the length was similar between bar spacings (70 mm: 53 cm, 60 mm: 53 cm, 55 mm: 50 cm). Data were collected in February/March 2006 and 2007 from 70 trawl deployments (45–270 min) on a research vessel using a twin trawl. Experimental codends with standard commercial steel grids of one of four bar spacings (80, 70, 65 and 55 mm) were fished on one side of the trawl and on the other a standard identical codend but without a grid and with a small mesh (55 mm) inner liner to retain all catch that entered the codend (see original paper for gear specifications).

A replicated, paired, controlled study in 2005 on bottom fishing grounds in the Skagerrak and Kattegat, Sweden (8) found that changing the design of size-sorting escape grids (two types) did not typically reduce the overall catches of discarded fish of five commercial species compared to a standard grid design. For one of two grid designs (flexible), average catch weights of discarded whiting *Merlangius merlangus* and haddock *Melanogrammus aeglefinus* were reduced compared to the standard (rigid) grid (flexible: 0.1–0.6 kg, standard: 0.6–1.6 kg), but cod *Gadus morhua* and hake *Merluccius merluccius* discards were similar between grids (flexible: 1.7–3.1 kg, standard: 1.6–3.8 kg) and plaice *Pleuronectes platessa* discards were higher in the flexible grid design (flexible: 2.3 kg, standard: 1.7 kg). For the other grid design (15 cm gap), no differences were found in average discarded weights of whiting, haddock and hake compared to the standard grid (gap: 0.0–0.2 kg, standard: 0.0–0.1 kg), but cod and plaice discards were higher (gap: 1.8–3.0 kg, standard: 1.0–1.3 kg). In addition, fewer discards of the target Norwegian lobster *Nephrops norvegicus* were caught with the flexible grid compared to the standard (23.3

vs 30.2 kg) and similar amounts with the gap grid (both 0.6 kg). Data were collected in June and November/December 2005, from 24 deployments of a twin trawl towing experimental nets and standard nets simultaneously at five locations in the Skagerrak and Kattegat. Experimental nets were fitted with one of two grid types: a flexible sorting grid (plastic, 35 mm bar spacing, ten hauls), and a rigid grid with a 15 cm open gap at the bottom (35 mm bar spacing, 14 hauls). The standard grids were aluminium (35 mm bar spacing). All nets had 70 mm square mesh codends.

A replicated, randomized, controlled study in 1995–1998 at multiple coastal sites in the Atlantic Ocean, USA (9) found that the effect of using different designs or configurations of size-sorting escape grid on reducing the amount of unwanted shark (Selachii) catch in shrimp trawl nets varied with the type of trawl net used. Across all grid and trawl net combinations, shark catch rates were lowest in mongoose commercial trawl nets fitted with a Georgia Jumper grid (2 sharks/net/h) and flat nets with a Super Shooter grid (2 sharks/net/h). Intermediate catch rates (similar to both the lowest and highest rates) were found for mongoose nets with a Super Shooter grid, either with (15 sharks/net/h) or without (17 sharks/net/h) an additional catch escape device (a Fish Eye). The highest catch rates were found for a triple-wing net with a Super Shooter grid (23 sharks/net/h). A subset of data (June-July) was taken from monthly shrimp trawl discard data collected during the shrimp trawling season (April-January) from 1995–1998, onboard vessels engaged in the shrimp *Penaeidae* fishery off Georgia. Catches sampled were randomly selected from one of three commercial shrimp trawl net designs: flat net, mongoose or triple wing trawls. Each used a Super Shooter escape grid, except some mongoose nets that used a Georgia Jumper grid. Both grid types were metal and oval but differed in the angle of the bars. Some mongoose net/Super Shooter combinations also included a 'Fish Eye' escape opening in the codend. Full details of trawl and grid designs are provided in the original study.

A replicated, paired, controlled study in 2010 of an area of seabed in the North Pacific Ocean off Newport, Oregon, USA (10) found that using a different configuration of size-sorting escape grid (decreased bar spacing) in a shrimp trawl net reduced the unwanted catch of eulachon *Thaleichthys pacificus* (focus species) and of three of five other fish species/groups. Catch rates with a grid of narrower 19 mm bar spacing were lower compared to a standard 25 mm grid, for eulachon (narrow: 319.2 kg/haul, standard: 382.5 kg/haul), slender sole *Lyopsetta exilis* (narrow: 0.4 kg/haul, standard: 0.6 kg/haul), other small flatfish (species not reported) (narrow: 0.1 kg/haul, standard: 0.5 kg/haul) and darkblotched rockfish *Sebastes crameri* (narrow: 21.2 kg/haul, standard: 89.2 kg/haul). Catch rates of whitebait smelt *Allosmerus elongatus* (narrow: 54.7 kg/haul, standard: 50.1 kg/haul) and juvenile Pacific hake *Merluccius productus* (narrow: 17.7 kg/haul, standard: 16.3 kg/haul) were similar between grids. Catches of the commercial target ocean shrimp *Pandalus jordani* were similar (narrow: 46.0 kg/haul, standard: 45.5 kg/haul). Data were collected in August–September 2010 from 30 paired deployments (45–60 min) on a shrimp trawler using a double-rigged net. Both sides of the net were identical and had a rigid grid. One side had 19 mm grid bar spacing and the other a standard 25 mm bar spacing, alternated every two hauls (see original paper for gear specifications). Catches from each net were sorted and weighed by species.

A replicated, paired, controlled study in 2009 of a seabed fishery in the Gulf of Maine, Atlantic Ocean, USA (11, same experimental set-up as 13 and 15) found that using a different (new) type of size-sorting escape grid in a shrimp trawl net where most of the net surrounding the grid was removed, reduced the unwanted catch of four of four fish species, compared to an existing grid design. Average catches of long rough dab *Hippoglossoides platessoides*, witch flounder *Glyptocephalus cynoglossus*, silver hake *Merluccius bilinearis*, and red hake *Urophycis chuss* were reduced by 36–50% with the new design of grid (new grid: 5.0–182.4 kg, old grid: 10.0–354.3 kg – see paper for species individual data). However, catches of the commercial target species northern shrimp *Pandalus borealis* were similar between grids (new grid: 2,446 kg, old grid: 2,528 kg). Between 3–12 May 2009, a total of 24 comparative deployments were made by an inshore shrimp trawler on a shrimp fishing ground, each of 1 h duration and between 137–165 m depth. A commercial shrimp trawl was modified with two codends; one with a new design of size-sorting grid and one with the old design (see original paper for gear specifications. After each deployment, codend catches of finfish and shrimp were sorted, weighed and lengths measured.

A replicated study in 2008–2009 of a pelagic area in the Gulf of Maine, Atlantic Ocean, USA (12) found that changing the design of an experimental size-sorting escape grid (grid colour, orientation and position of escape vent) in a fish trawl did not typically reduce the unwanted catch of spiny dogfish *Squalus acanthias* between grid designs. Overall, >88% of dogfish that entered the trawl net were excluded by the size-sorting grid, regardless of grid colour or design configuration (data presented graphically). However, a black grate with an escape opening in the bottom of the trawl had a higher ratio of dogfish reduction than black top opening grids and white grids with either top or bottom openings (data not tested for statistical difference). Two fishing trials were done in the Gulf of Maine in October–November 2008 and July–August 2009 using trawl nets designed for commercial targeting of silver hake *Merluccius bilinearis*. The trawl nets were modified with a polyethylene grid, with 51 mm bar spacing, inserted into the extension piece in front of a small diamond mesh (51 mm) codend. Different grid colours (black and white), configurations of grid angle (35° and 45°) and location of the escape opening (top and bottom) were tested. Thirty-two valid hauls were completed. An underwater camera attached in front of the grid collected video data in 30 hauls. Dogfish escaping through the grid were recorded from review of the video data.

A replicated, paired, controlled study in 2009 of a fished area of seabed in the Gulf of Maine off Portland, USA (13, same experimental set-up as 11 and 15) found that using a different configuration of size-sorting escape grid in a dual-grid system (decreased bar spacing in a secondary grid designed to reduce the catches of small target shrimp) had no effect on the capture of non-commercial target finfish, compared to a standard bar spacing. There were no differences in average catch rates of the three main unwanted finfish species and all other unwanted finfish catch combined between a narrower 9 mm grid bar spacing and a standard 11 mm grid bar spacing: silver hake *Merluccius bilinearis* (narrow: 3.8 kg/h, standard: 4.3 kg/h), long rough dab *Hippoglossoides platessoides* (narrow: 1.3 kg/h, standard: 1.2 kg/h), witch flounder *Glyptocephalus cynoglossus* (narrow: 0.4 kg/h, standard: 0.3 kg/h), and all other finfish (narrow: 0.4 kg/h, standard: 0.5 kg/h). In addition, average catch rate of the commercial target species Northern shrimp *Pandalus borealis* were similar (narrow: 82.7 kg/h, standard: 77.8 kg/h). Data were collected in between 20 April and 2 May 2009 from 24 comparative deployments (1 h) using a commercial shrimp trawl net modified to have two codends. In each codend, one of two rectangular size-sorting grids with different grid spacing (9 mm and 11 mm) were fitted. In both codends, the size-sorting grid was installed in front of a standard grid (Nordmøre), creating a dual-grid system (see paper for gear specifications). Catches in each codend were sorted and weighed by the main non-target finfish and commercial target shrimp species.

A replicated, paired, controlled study in 2010 of a sandy seabed area in the Atlantic Ocean, off Brazil (14) found that using a different configuration of size-sorting escape grid (decreased bar spacing) in shrimp nets in a traditional canoe-trawl fishery did not reduce the total catches of non-target fish compared to a standard bar spacing. The average catch weight of all ray-finned fish (*Teleostei*) combined was similar between narrower grid bar spacings (20 mm and 17 mm) compared to the standard 24 mm (17 mm: 1.0 kg/30 min, 20 mm: 1.3 kg/30 min, 24 mm: 1.2 kg/30 min). In addition, commercial target catches of seabob shrimp *Xiphopenaeus kroyeri* were similar between grid bar spacings (17 mm: 5.5 kg/30 min, 20 mm: 5.0 kg/30 min, 24 mm: 5.5 kg/30 min). Data were collected in April–June 2010 from 24 paired trawl deployments on a powered fiberglass canoe rigged with two identical trawl nets (26 mm codend). One trawl was fitted with a plastic grid (Nordmøre type) of one of three different bar spacings: 17 mm, 20 mm and an existing 24 mm. The other trawl had no grid. The grid trawls were alternately compared against each other and the no grid trawl (see original paper for gear specifications). Codend catches were separated by groups of organisms and the numbers and weights of each group recorded.

A replicated, paired, controlled study in 2009 of a fished area of seabed in the Gulf of Maine, Atlantic Ocean, USA (15, same experimental set-up as 11 and 13) found that using a different type of size-sorting escape grid system (two grids) in shrimp trawl nets reduced the capture of unwanted finfish compared to a trawl net fitted with a conventional grid design. Overall, average catch rates of all unwanted finfish species, including smaller individuals of key species of commercial importance (see paper for list of species), was reduced by 33% in the trawl net with two grids compared to one grid (two grids: 23 kg/h, one grid: 33 kg/h). In addition, overall average catch rates of the target commercial species Northern shrimp *Pandalus borealis* were lower with the dual-grid system (two grids: 80 kg/h, one grid: 91 kg/h), but fewer smaller shrimp (<27 mm carapace length) were caught. Data were collected from 24 comparative trawl deployments done between 13 to 24 May 2009 on shrimp fishing grounds. A commercial shrimp trawl net modified with two codends was towed for 1 h at 135–163 m depth. One codend was fitted with an experimental combination grid system made from a rope grid - a 25 mm-spaced standard (Nordmøre) grid with two-thirds of the netting around it cut away and replaced with four ropes - and an additional 9 mm-spaced polyethylene grid in front of the rope grid. The other codend was the standard Nordmøre grid, with 25 mm bar (see paper for gear specifications). Numbers, weights and lengths of individuals of the non-target finfish and target shrimp species were recorded.

A replicated study in 1992 in waters in the Northeast Atlantic off Norway (16) found that using a different configuration of size-sorting escape grid (increased bar spacing) in a fish trawl improved the size-selectivity of unwanted redfish *Sebastes* spp. The average length at which redfish had a 50% chance of escape via the grid was greater for the widest bar spacing and increased with increasing bar spacing (50 mm: 35 cm, 45 mm: 30 cm, 40 mm: 28 cm). Data were collected in March 1992 from 17 deployments of a trawl fitted with a two-grid size-sorting system (Sort-X) of one of three grid bar spacings: 50 mm (12 hauls), 45 mm grid (three hauls) and 40 mm grid (two hauls). A small mesh cover attached over the grid collected fish escaping through it while a small mesh inner lining in the codend prevented fish escaping through the codend meshes. The number and lengths of redfish collected in both the cover and codend were recorded.

A replicated study in 1994–2011 of two seabed areas in the Norwegian and Barents Sea, Norway (17) found that two different types of commercially used size-sorting escape grid systems in fish trawl nets had different size-selectivities for unwanted Greenland halibut *Reinhardtius hippoglossoides*. The length at which halibut had a 50% chance of escaping through the grid (fish >30 cm only) was greater with a 'Sort-V' grid system compared to a 'Sort-X' grid system (Sort-V: 59–67 cm, Sort-X: 42–56 cm). In addition, it was found that this may be due to differences in the body orientation of halibut between grids to give the optimum angle for escape. Two sets of trials were conducted on different vessels, fishing in separate areas and with different trawl gears in November 1994 and October 2011. In 1994, four deployments were done on fishing grounds near Tromsøflaket using a trawl net fitted with a 'Sort-X' escape grid system, consisting of two grid sections and a canvas guiding section. In 2011, six deployments were completed on the banks of Hopendjupet, using a Sort-V grid system comprising one grid attached to a mesh guiding panel behind a mesh lifting panel (see paper for gear specifications). For both grid systems, the grid had 55 mm bar spacing, and halibut escaping from them were collected in mesh covers installed over the escape openings. Codends were fitted with a small-mesh inner bag to sample retained fish. Halibut from the cover and codend catches were counted and length measured.

A replicated, controlled study in 2015 of two seabed areas in the Norwegian and Barents Sea, off Norway (18) found that using a new type of size-sorting escape grid system (four panel double grid) did not improve the size-selectivity of unwanted redfish *Sebastes* spp., compared to two existing commercial grid systems. The likelihood of redfish being retained at any given length was similar between the new double grid system compared to one of two existing grid systems (Sort-X), but compared to the other existing grid (Sort-V), the new grid retained more redfish between 35–50 cm (data presented as retention probability curves). Data were collected for the new double grid system in February-March 2015, from a total of 19 trawl deployments by a trawler on fishing grounds off the coast of Finnmark and Troms, north Norway. The gear used was a four-panel section of net with two steel sorting grids (upper and lower) fitted in front of a 138 mm diamond mesh codend. The lower grid had 55 mm bar spacing and replaced the polyethylene lifting panel of an existing mandatory steel grid section, and the upper grid was a standard steel grid (Sort-V type) with 55 mm bar spacing (see paper for specifications). Two small mesh covers over each grid collected fish escaping through them. The lengths of redfish >20 cm caught in the codend and covers were measured. Escape data were compared with data previously obtained for single Sort-V and Sort-X grid systems (see original paper for details).

A replicated, controlled study in 2014 in two areas of seabed in the Barents Sea off Norway (19) found that using a new type of size-sorting escape grid system (four panel flexigrid) improved the size-selectivity of undersized cod *Gadus morhua* but not haddock *Melanogrammus aeglefinus* compared to a conventional two panel design. For cod, the length at which fish had a 50% chance of escape from the combined grids of the new four panel system was greater compared to the conventional grid system in one of two trials (new: 42 cm, conventional: 18 cm) and was similar in the other (new: 36 cm, conventional: 31 cm). For haddock, there was no difference in the 50% escape length between grid systems in one of one trial at Bear Island (new: 36 cm, conventional: 33 cm). In addition, the four panel grid system retained fewer undersized cod than the conventional grid, but there were no differences in the sizes of haddock caught between grids (data reported as selectivity curves). Data were collected in October 2014 from 51 trawl deployments on a commercial trawler on two separate fishing grounds around Bear Island and Hopen. Separate deployments were made using either a trawl net with a new four panel flexible double grid system (28 hauls) or a conventional two panel system (23 hauls). Both trawls had 138 mm diamond mesh codends. See original paper for full gear specifications. Small mesh covers over each of the grids collected fish escaping through each grid system. The lengths of cod and haddock retained in the codends and covers were measured.

A replicated, paired study in 2010 in an area of seabed in the Kattegat and Skagerrak, Denmark (20) found that the effect of using a different type of size-sorting escape grid system (three designs) in a prawn trawl net on the reduction of unwanted fish catch varied between species. The average percentage escape of small or undersized fish was higher for grids with horizontal and vertical bars than a grid with vertical bars and a guiding funnel, for three of five species (horizontal: 59–88%, vertical: 79–87%, vertical with panel: 35–55%). For one species escape of undersized fish was higher with the horizontal bar grid than either of the other two grids (horizontal: 85%, vertical: 67%, vertical with funnel: 48%) and for the other species escape rate of small individuals was not statistically different between all three grids (horizontal: 86%, vertical: 75%, vertical with funnel: 55%). In addition, escape of undersized individuals of the commercial target species Norway lobster *Nephrops norvegicus* was higher with the vertical bar grid (17%) than the other two grids (horizontal: 5%, vertical with funnel: 6%). There were also high losses of commercial sized catch in some cases (see paper for data). Sea trials took place in March 2010 on a commercial trawler rigged with a twin-trawl system. Thirty-four trawl deployments (2–4 h) were completed using three designs of flexible grid: horizontal bars (10 tows), vertical bars (12 tows) and vertical bars with a guiding funnel (14 tows). Both grids with vertical bars were fished simultaneously on each side of the trawl, while the horizontal grid was fished with a codend being used for another experiment. A small mesh cover installed over the escape openings collected individuals escaping from the grids. All grids were installed at a 45° angle with bar spacing of 45 mm (see original paper for gear specifications).

A replicated, controlled study in 2012 of an area of seabed in the Indian Ocean off north east Australia (21) found that using a different type of size-sorting escape grid system (upward-angled) reduced the capture of two of four groups of unwanted sharks and rays (Chondrichthyes) compared to two (one modified and one standard) downward-angled escape grids. The percentages of individuals that escaped was greater from an upward-angled grid compared to the two downward grids (one with square mesh) for two groups of fish: 'benthopelagic' sharks that feed on bottom and free swimming prey (up: 50%, down: 25%, square mesh: 28%) and shark-like rays (up: 53%, down: 28%, square mesh: 25%). There were no differences in escape rates between grids for rays and skates (up: 72%, down: 67%, square mesh: 70%) or bottom-dwelling sharks (up: 82%, down: 78%, square mesh: 80%). From June–December 2012, three vessels completed a total of 774 deployments of trawl nets fitted with one of three catch escape devices: upward opening/inclined rigid escape grid (218 hauls), a standard semi-rigid downward grid used in the bottom trawl fishery (301 hauls), and a rigid grid (same as upward) modified in a downward inclined orientation and stitched into a section of 50 mm square mesh (255 hauls). See original paper for gear specifications. Escapes of sharks/rays were monitored using video footage recorded from within the nets and onboard the vessels.

A replicated study in 2008 in an area of seabed in the Gulf of Cádiz, Atlantic Ocean, Spain (22) found that using a different configuration of size-sorting escape grid (increased bar spacing) in a multi-species trawl fishery improved the size-selectivity of European hake *Merluccius merluccius*. The length at which hake had a 50% chance of escaping through the grid increased with increasing grid bar spacing (50 mm: 42 cm, 40 mm: 36 cm, 30 mm: 30 cm, 25 mm: 27 cm). Data were collected in July–September 2008 from 282 trawl deployments (1–7 h) on four fishing vessels. The vessels fished using trawl nets fitted with a size-sorting grid system (Sort-X design) of one of four different grid bar spacings (50, 40, 30 and 25 mm). A small mesh (20 mm) cover attached over the grid collected fish escaping through the grid bars and a small mesh inner net in the codend collected larger fish retained by the grid (see original paper for gear specifications). The numbers, weights and lengths of hake in the covers and codends were recorded. At the time of study, minimum landing size for hake in the area was 27 cm.

A controlled study in 2016 of a fished area of seabed in the Barents Sea, Norway (23) found that that using a different type of size-sorting escape grid system (two grids) in shrimp trawls increased the escape of small immature redfish *Sebastes* spp. and long rough dab *Hippoglossoides platessoides*, compared to a standard single grid. For small (<10 cm) redfish and long rough dab, the likelihood of being retained in the codend was lower with the dual grid system combined compared to the single grid (data reported as retention probability curves). The proportion of redfish and long rough dab that escaped through the additional second grid was 32% and 16% respectively. The length at which fish had a 50% chance of escape through the second grid was 8 cm for redfish and 10 cm for long rough dab, compared to 14 cm and 18 cm respectively with the single grid (i.e. only the smallest fish escaped from the second grid). Data were collected in February 2016, from eight deployments (1 h) of a trawl net fitted with the double grid system, consisting of a 0.75 × 1.5 m standard escape grid (Nordmøre, 19 mm bar spacing, upward opening), followed by a second 0.6 × 1.2 m 'release' grid (9 mm bar spacing, bottom opening). A guiding mesh panel directed catch to the bottom of the Nordmøre grid. Covers attached over the openings of each grid collected fish escaping through them. The codend was fitted with a small mesh liner to prevent fish escaping through the codend meshes (see original paper for gear specifications). The lengths of fish retained in the covers and codend were measured.

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2.65 Fit a moving device to a trawl net to stimulate fish escape response (stimulator device)

- **Three studies** examined the effects of fitting a moving device to a trawl net to stimulate fish escape response (stimulator device) on marine fish populations. Two studies were conducted in laboratory facilities[1,3] (South Korea) and one study was in the Baltic Sea[2] (Northern Europe).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (3 STUDIES)

- **Reduction of unwanted catch (2 studies):** Two replicated, controlled studies in a laboratory[1,3] found that trawl nets fitted with moving devices to stimulate fish escape response increased the escape of young red seabream[1,3] compared to without devices, but for young olive flounder moving devices were only effective at increasing escape when used in combination with another novel device that made the net shake[3].
- **Improved size-selectivity of fishing gear (1 study):** One replicated, controlled study in the Baltic Sea[2] found that only one of three types of moving stimulator devices fitted in conjunction with square mesh escape panels improved the size selectivity for cod, compared to without devices.

Background

Trawl nets, particularly in fisheries targeting small crustaceans such as prawns and shrimps, can also catch large amounts of unwanted small fish. To try and reduce this, various 'bycatch reduction devices' have been developed that force or encourage fish to escape through specific areas or sections of the net. Introducing an active stimulus, i.e. moving and/or vibrating parts, inside a net may be a way of encouraging fish to approach and make contact with the trawl netting (and thus increase the likelihood of escape through it), and works by creating either a barrier or vibrations that stimulate fish to swim in a particular direction. They may consist of fluttering sections of netting or rope, or tightly strung wires. Active stimulating devices may be used in addition to other bycatch reduction devices such as square mesh windows or grids, to herd fish towards the escape openings.

A replicated, controlled study in 2009 in laboratory facilities in Tongyoung, South Korea (1) found that trawl net codends fitted with moving devices to stimulate fish escape response (active stimulating devices) increased the escape of immature red seabream *Pagrus major* compared to conventional trawls, and the effect was influenced by mesh size and light level. In a 28 mm mesh codend, fewer immature seabream were retained with a stimulating device than without in dark and bright conditions (dark: 74 vs 83%, bright: 80 vs 87%). However, there was no statistical difference in dim light (device: 66, without: 82 %). For a 43 mm mesh, the codend with a stimulating device retained fewer seabream than a conventional codend in all light conditions (dark: 78 vs 87%, dim: 46 vs 65%, bright: 37 vs 49%). In 2009, groups of immature seabream were released into 40 cm diameter codends (28 mm or 43 mm mesh size) in a laboratory tank. For each mesh size, codends with and without one of two active stimulating devices (fluttering panels of netting, 60 x 40 cm; and an array of 11 ropes, 70 cm long) were tested at one of three light conditions (dark, dim, bright). Each trial was repeated 10 times for random groups of fish (120 trials) with 200 fish released into the codend each time.

A replicated, controlled study in 2012 of a seabed area in the Arkona Basin, western Baltic Sea, Northern Europe (2) found that only one of three designs of moving devices to stimulate fish escape response (active stimulating devices) fitted to trawl net codends in tandem with a square mesh escape panel improved the size selectivity of cod *Gadus morhua* compared to a codend without a device. The length at which cod had a 50% chance of escaping (selection length) was greater with float ropes as the stimulating device, for two different sizes of catch (200 kg: 36.7 cm, 700 kg: 38.3 cm) compared to the two other devices (fluttering rope and inclined panel) and without a device, which did not differ from each other (200 kg: 29.5 cm, 700 kg: 31.0 cm). Experimental fishing trials were done in March/April and September 2012. Deployments were made of four identical codends with a 120 mm top square mesh escape panel in the front of the codend and with or without an active stimulating device. Three codends with devices were tested: fluttering ropes (8 tows), an inclined panel (5 tows) and float ropes (3 tows), and one without (11 tows). See paper for gear specifications. A cover mounted over each codend collected the escaping cod. Catches from both codends and covers were sorted, and cod length and number recorded.

A replicated, controlled study in 2012 at an experimental tank facility in Tongyoung, South Korea (3) found that trawl net codends fitted with moving devices (two types) to stimulate fish escape response (active stimulating devices) increased the escape of young red seabream *Pagrus major* compared to conventional codends, but for young olive flounder *Paralichthys olivaceus* they were only effective when used in combination with an additional device that generated an active shaking motion of the net. For seabream, overall escape rates from the codend were higher with a stimulator device than without (with: 40–62%, without: 13–43%), but there was no difference for olive flounder (with: 55–88%, without: 60–87%). However, for both species the escape rates were greater in codends, with or without stimulator devices, fitted with another device that made the nets shake (seabream, shaking: 38–62%, steady: 13–40%; flounder, shaking: 55–63, steady: 85–88%), with the exception of seabream in a shaking codend with stimulator device at the faster of two flow rates (shaking: 38%, steady: 32%). In October 2012, seven separate experiments were done in circular water tanks to test a new method (shaking of the codend generated by a cap-like canvas fitted at the end) of increasing the escape of young fish from three types of codend: two with active stimulator devices (a fluttering flag-like netting panel and a double conical rope array – see paper for specifications); and one conventional codend without a device. In each experiment, a group of 200 hatchery-reared fish were released into the water flow at the front of the codend and the number of fish retained/escaped were recorded. Three flounder experiments with all three types of codend and shaking or steady motion were tested at the same water flow rate (0.6 m/s). For seabream, a conventional codend and a net stimulator device were each tested at two different water flow rates (0.5 and 0.7 m/s).

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Alternative harvesting methods

2.66 Use an alternative commercial fishing method

- **Nine studies** examined the effects of using an alternative commercial fishing method on marine fish populations. One study was in each of the Arafura Sea[1] (Australia), the Greenland and Norwegian Seas[2] (Norway), the Norwegian Sea[3] (Norway), the Atlantic Ocean[4] (Portugal), the Mediterranean

Sea[5] (Italy), the Gulf of Maine[6] (USA), the Coral Sea[7] (Australia), the Tyrrhenian Sea[8] (Italy) and the Kattegat and Skagerrak[9] (Sweden).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (9 STUDIES)

- **Reduction of unwanted catch (9 studies):** Seven of nine replicated studies (two controlled, one randomized, controlled, one paired, controlled) in the Arafura Sea[1], Greenland/Norwegian Sea[2], Norwegian Sea[3], Atlantic Ocean[4], Mediterranean Sea[5], Gulf of Maine[6], Coral Sea[7], Tyrrhenian Sea[8] and Kattegat and Skagerrak[9] found that using an alternative method of fishing caught fewer discarded fish species[4] and reduced the catches of unwanted (discarded or non-commercial species) fish overall[1,4,9], and of immature halibut[2], haddock[3], cod[3,6], bluefin tuna[8] and over half of the individual fish species[1]. One study[7] found that an alternative fishing method caught larger (and more likely to be mature) unwanted hammerhead sharks. The other study[5] found that sizes of striped sea bream, annular sea bream and red mullet were similar in catches between gear types.

Background

Almost all fishing methods catch small or unwanted fish that are thrown back into the sea after capture. There are many different types of fishing gear including trawls, which are towed through the water or over the seabed, traps which are usually baited and left on the seabed for a period of time, lines with baited hooks, and nets which can be left in the water or towed by fishing vessels to encircle schools of fish. Some types of fishing gears are more selective than others (i.e. they are better at only catching the desired species for market) and using an alternative type of fishing gear to catch the same commercially targeted fish could reduce the catches of unwanted fish.

Evidence for a similar intervention is summarized under *'Alternative harvesting methods - Use hook and line fishing instead of other commercial fishing methods'.* See also *'Fishing gear modification - Use a separator trawl; Use a topless (coverless) trawl'* and *'Use an electric (pulse) trawl'*.

A replicated, controlled study in 1991 of fishing grounds over mud and coral reef in the Arafura Sea, off Northern Australia (1) found that using an alternative method of fishing (semi-pelagic trawl, towed just above the seabed) to target snapper *Lutjanus* spp. reduced the unwanted fish catch overall, and of just over half of the species individually, compared to traditional demersal (bottom-towed) trawls. Catch rates of unwanted fish were lower in semi-pelagic trawls (195 kg/tow) than traditional demersal trawls (453 kg/tow). Catch rates of 75 unwanted fish species were lower in semi-pelagic trawls, 52 fish species were similar between trawl types, and seven species were caught more frequently in semi-pelagic trawls (see paper for species individual data). In addition, catches of marketable commercial fish were similar between trawl types for 10 of 16 species groups (semi-pelagic trawl: 392 kg/tow, demersal trawl: 320 kg/tow). Fourteen tows were undertaken in March 1991 for each of a semi-pelagic trawl (0.3 m above the seabed) with a buoyed headline, and a traditional demersal trawl. Both trawl nets had a similar codend volume with 112 mm mesh size, 65 m trawl widths and were towed for 3

h. Full details of trawl design are provided in the original study. All catches were weighed, and fish identified.

A replicated study in 1994 of a wide area of seabed in the Greenland and Norwegian Seas, Norway (2) found that fishing using gillnets reduced the capture of unwanted, immature Greenland halibut *Reinhardtius hippoglossoides,* compared to trawling or longlining. Gillnets caught lower proportions of immature halibut (male: 0%, *n*=411; female: 6%, *n*=5,740) than longlines (male: 21%, *n*=1,485, female: 23%, *n*=4,661) and trawls (male: 37%, *n*=3,309; female: 71%, *n*=2,402). In addition, the average length of halibut caught was higher for gillnets (66 cm) compared to trawl- (50 cm) and longline-caught halibut (60 cm). Data were collected from scientific fishing deployments using three different gears in August–September 1994 at different water depths (400–1,400 m). A total of 130 deployments were made of gillnet fleets with 70–110 mm mesh sizes, 71 sets of longlines totalling 335,310 hooks baited with mackerel and squid (species not given), and 70 deployments by a trawler towing a 136 mm mesh codend. Haul speed and duration were not given.

A replicated study in 1996 of a seabed area in the Norwegian Sea, off northern Norway (3) found that fishing using gillnets reduced the capture of small, unwanted cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* compared to trawling or longlining. In two of two trials, gillnets caught larger cod than trawls or longlines (gillnet: 82–86 cm, trawl: 67-69 cm, longline: 68–69 cm). In addition, gillnets caught fewer cod compared to trawls in both cases, and similar amounts in one case and more in one case compared to longlines (gillnet: 1,657–3,391 kg, trawl: 3,238–4,096 kg, longline: 1,773–1,754 kg) (data were not tested for statistical significance). Trawls captured larger haddock than longlines in one case, and smaller in one case (trawl: 53 cm, longline: 51–55 cm,). Fewer haddock were caught in longlines compared to trawls in both cases (longline: 665–1,055 kg, trawl: 1,153–1,973 kg) (data not tested for significance). Three fishing vessels tested a different gear type in one area of 10 × 40 nautical miles in February 1996 over six days. Depths were between 227–259 m. The gillnetter fished nine fleets of 186 mm mesh and two fleets of 200 mm mesh. The longliner used squid and mackerel bait on fleets of 6,300 or 8,230 hooks; 26 fleets were fished. The trawler fishes a standard trawl with a twin codend and 140 mm mesh size.

A replicated, randomized controlled study in 1996–1997 of an area of pelagic water in the Atlantic Ocean, off Portugal (4) reported that pelagic purse seine nets appeared to discard fewer species of cartilaginous fish (Chondrichthyes) such as sharks and rays, and bony fish (Osteichthyes) compared to other types of fishing gear. Data were not tested for statistical significance. For shark/ray species, of which 85% were usually discarded, 1 species was caught in pelagic purse seines, 2 in demersal purse seines, 7 in trammel nets, 10 in fish trawls and 13 in crustacean trawls. For bony fish, of which 34% were usually discarded and 54% frequently discarded, 34 species were caught in pelagic purse seines, 55 in both demersal purse seines and crustacean trawls, 49 in trammel nets and 66 in fish trawls. In March 1996 to June 1997, a total of 57 fishing trips on 24 vessels were sampled at random by fisheries observers in Algarve waters. Overall, data were collected from 18 pelagic purse seine sets, 33 demersal purse seine sets, 11 trammel net sets, 30 crustacean trawl tows and 36 fish trawl deployments. All fish were identified and counted. Fished depths were 30–500 m, depending on gear type. Due to the variety of vessels and gears sampled, specific gear details were not given in the original paper.

A replicated, paired, controlled study in 1996–1997 of two coastal areas of the Mediterranean Sea, Italy (5) found that a gillnet, a modified trammel net and a standard trammel net caught similar average sizes of striped sea bream *Lithognathus mormyrus*, annular sea bream *Diplodus annularis* and red mullet *Mullus barbatus*. Across areas and for the same mesh size, average sizes of all species were similar between the gillnet and trammel nets: striped bream (45 mm, gillnet: 16–17 cm, trammel nets: 16–18 cm; 70 mm, gillnet: 25–26 cm, trammel nets: 23–26 cm), annular bream (45 mm only, gillnet: 12–13 cm, trammel nets: 12–14 cm) and red mullet (45 mm only, gillnet: 16 cm, trammel nets: 15–16 cm). Between March 1996 and June 1997, a total of 29 trials were carried out in the Adriatic and 43 in the Ligurian Sea. A gillnet with one monofilament panel, a trammel net with an inner panel of polyamide monofilament and outer panels of twisted polyamide filament, and a standard commercial trammel net with all panels made of twisted polyamide filament, were tied end-to-end and their positions changed for each trial. The nets were lowered into shallow (4–15 m) water at dusk and retrieved the following dawn. All fish were identified, and fish length measured.

A replicated study in 2005–2006 of four seabed areas in the Gulf of Maine, USA (6) found that fishing using longlines reduced the capture of unwanted cod *Gadus morhua* compared to otter trawls in a haddock *Melanogrammus aeglefinus* fishery. In all four areas fished, the ratio of cod weight to haddock weight was smallest with a longline compared to an otter trawl (longline: 0.01–0.07 otter trawl: 0.2–0.83 cod/haddock caught). In addition, the ratio of cod weight to all target species (including winter flounder *Pseudopleuronectes americanus* and yellowtail flounder *Limanda ferruginea*) was smallest when using a longline (longline: 0.01–0.05, otter trawl: 0.2–0.46). In June 2005 - January 2006 a total of 146 longline hauls and 159 otter trawl hauls were sampled on the Georges Bank. All longliners fished with 12/0 circle hooks. Longliners fished mainly in depths shallower than 50 m whereas otter trawlers fished in deeper waters also. Data were obtained from fishers and fisheries observers. Specifications of the otter trawl gears were not described.

A replicated study in 1996–2006 in 10 shallow coastal areas in the Coral Sea off the northeast coast of Australia (7) found that drumlines caught larger individuals of scalloped hammerhead shark *Sphyrna lewini,* compared to surface mesh nets. Average shark length was greater in drumlines (2.1 m) than mesh nets (1.9 m). Size at maturity for the region was reported to be from 2.0 m total length for females and from 1.8 m total length for males. A total of 128 sharks were caught in drumlines and 350 in mesh nets. Data were collected from 344 drumline and 35 mesh net deployments operated by the Queensland Shark Control Program at 10 locations along the east coast of Queensland between 1996 and 2006. Individual drumlines consisted of a single baited hook suspended by chain, two metres below a float anchored to the seabed. Bait was 1–2 kg of mullet *Mugil cephalus* or shark flesh (species not given). Mesh nets were 186 m long and 6 m deep (mesh 0.5 m). Gears were deployed in 8–10 m depth, 300–1,000 m from, and parallel to, the beach. Both gears were checked by trained fishing contractors and drumlines rebaited, on 15–20 days each month. Full gear specifications are given in the paper.

A replicated, controlled study in 2003 of a pelagic area in the Tyrrhenian Sea, Italy (8) found that using a different type of seine net reduced the capture of Atlantic bluefin tuna *Thunnus thynnus* compared to a conventional seine net in the dolphinfish *Coryphaena hippurus* net fishery. Numbers of tuna captured were lower in the modified net compared to the conventional net (modified: 1 fish, conventional: 5–11 fish). Numbers of commercial target dolphinfish captured were similar between gear types (modified: 85–270 fish, conventional: 86–268 fish). In August–November 2003, a modified seine net with a 15 mm mesh coded and 30 mm side meshes, and a conventional purse seine with a of 30 mm mesh codend and two 50 mm side meshes were deployed off Capo d'Orlando, Sicily, in depths of 600–800 m. In total, 48 hauls were carried out, six hauls/gear type/month. Anchored palm leaves *Phoenix canariensis* were placed 500 m from each other to attract fish. Nets were placed around the batches of palm leaves. Fish were counted and lengths measured.

A replicated study in 2011–2013 in seabed areas in Kattegat and Skagerrak, Sweden (9) found that fishing for Norway lobster *Nephrops norvegicus* with baited creels reduced the capture of unwanted fish compared to bottom trawling using a size-sorting escape grids and mixed bottom trawling. The amount of catch discarded/landed amount of *Nephrops* was lower in creels (sharks/rays *Elasmobranchii*: 0.00, plaice *Pleuronectes platessa*: 0.00, sole *Solea solea*: 0.00, other flatfish: 0.01, cod *Gadus morhua*: 0.07, other cod-like fish: 0.02 kg discard/kg landed *Nephrops*) compared to both trawling types, and highest with mixed trawling (grid trawling, sharks/rays: 0.00, plaice: 0.15, sole: 0.01, other flatfish: 0.86, cod: 0.06, other gadoid fish: 0.10 kg discard/kg landed *Nephrops*; mixed trawling, sharks/rays: 0.15, plaice: 0.44, sole: 0.02, other flatfish: 0.75, cod: 0.51, other cod-like fish: 0.55 kg discard/kg landed *Nephrops*). In addition, discarded Norway lobster was reduced in creels (creels: 0.13, grid and mixed trawling: 0.71 kg discard/kg and average size was larger (creel: 46 mm, grid trawl: 38 mm, mixed trawl: 38 mm). Data were obtained from the Swedish fishing fleet logbooks between 2011 and 2013. Typically, mixed trawlers used a minimum mesh size of 90 mm with selective panels of various sizes fitted. Grid trawlers used a 35 mm Swedish grid and a 70–89 mm square mesh codend. Creels were static, baited pots arranged as 40–70 connected pots.

(1) Ramm D.C., Mounsey R.P., Xiao Y. & Poole S.E. (1993) Use of a semi-pelagic trawl in a tropical demersal trawl fishery. *Fisheries Research*, 15, 301–313.

(2) Huse I., Gundersen A.C. & Nedreaas K.H. (1999) Relative selectivity of Greenland halibut (*Reinhardtius hippoglossoides*, Walbaum) by trawls, longlines and gillnets. *Fisheries Research*, 44, 75–93.

(3) Huse I., Løkkeborg S. & Soldal A.V. (2000) Relative selectivity in trawl, longline and gillnet fisheries for cod and haddock. *ICES Journal of Marine Science,* 57, 1271–1282.

(4) Erzini K., Costa M.E., Bentes L. & Borges T.C. (2002) A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). *Fisheries Management and Ecology,* 9, 31–40.

(5) Fabi G., Sbrana M., Biagi F., Grati F., Leonori I. & Sartor P. (2002) Trammel net and gill net selectivity for *Lithognathus mormyrus* (L., 1758), *Diplodus annularis* (L., 1758) and *Mullus barbatus* (L., 1758) in the Adriatic and Ligurian seas. *Fisheries Research*, 54, 375–388.

(6) Ford J.S., Rudolph T. & Fuller S.D. (2008) Cod bycatch in otter trawls and in longlines with different bait types in the Georges Bank haddock fishery. *Fisheries Research*, 94, 184–189.

(7) Noriega R., Werry J.M., Sumpton W., Mayer D. & Lee S.Y. (2011) Trends in annual CPUE and evidence of sex and size segregation of *Sphyrna lewini*: Management implications in coastal waters of northeastern Australia. *Fisheries Research*, 110, 472–477.

(8) Sinopoli M., Castriota L., Vivona P., Gristina M. & Andaloro F. (2012) Assessing the fish assemblage associated with FADs (Fish Aggregating Devices) in the southern Tyrrhenian Sea using two different professional fishing gears. *Fisheries Research*, 123–124, 56–61.

(9) Hornborg S., Jonsson P., Sköld M., Ulmestrand M., Valentinsson D., Eigaard O.R., Feekings J., Nielsen J.R., Bastardie F. & Lövgren J. (2017) New policies may call for new approaches: the case of the Swedish Norway lobster (*Nephrops norvegicus*) fisheries in the Kattegat and Skagerrak. *ICES Journal of Marine Science,* 74, 134–145.

2.67 Use an alternative method to commercially harvest plankton

- **One study** examined the effect of using an alternative method to commercially harvest plankton on marine fish populations. The study was in the Norwegian Sea[1] (Norway).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (1 STUDY)

- **Reduction of unwanted catch (1 study):** One controlled study in the Norwegian Sea[1] found that the amount of unwanted fish larvae and eggs in fine-mesh catches of zooplankton were reduced after deployment of a bubble-plume harvester, compared to without deployment.

Background

Zooplankton (tiny drifting organisms) is a valuable source of protein and is harvested in the wild for use as aquaculture feed and pet fish food (Wiborg 1976). Fishing for zooplankton is done using fine-meshed trawls that results in lots of unwanted organisms being caught, including fish eggs and larvae. To help reduce mortality of unwanted fish eggs and larvae, an alternative method of plankton harvesting using air bubbles may enable selective transport in the water column of the targeted zooplankton such as copepods, up towards the surface (bubble flotation method). These can then be harvested by a plankton trawl leaving the fish eggs and larvae untouched at lower depths.

Wiborg K. F. (1976) Fishery and commercial exploitation of *Calanus finmarchius* in Norway. *ICES Journal of Marine Science*, 36, 251–258.

A replicated, controlled study in 2008 of pelagic waters in the Norwegian Sea, Norway (1) found that using a bubble-plume harvester in combination with fine-meshed trawls to harvest *Calanus* spp. zooplankton reduced the amount of unwanted fish larvae and eggs caught compared to using only fine-meshed trawls. Data were not tested for statistical significance. Fewer fish larvae and eggs were caught after the bubble raft was deployed compared to without deployment of the bubble raft, at all depths tested: 25 m (larvae: 70%, eggs: 98% reduction); 15 m (larvae: 96%, eggs: 94% reduction); and 10 m (larvae: 12%, eggs: 92% reduction). Catches of target *Calanus* spp. were between 30–130% higher in nets after bubble harvesting. In June 2008, a bubble raft was towed at three depths (25, 15, 10 m) by a research vessel. Standard plankton nets (20 cm diameter, 0.5 mm mesh) were towed for 30 min before and after the bubble raft was deployed (number of hauls not reported) and target *Calanus* spp. and non-target catches compared. The bubble raft produced 0.5–1 mm bubbles from eight perforated hoses towed in parallel. Full details of the bubble raft design are provided in the original paper.

(1) Grimaldo E., Leifer I., Gjøsund S.H., Larsen R.B., Jeuthe H. & Basedow S. (2011) Field demonstration of a novel towed, area bubble-plume zooplankton (*Calanus sp.*) harvester. *Fisheries Research*, 107, 147–158.

2.68 Use hook and line fishing instead of other commercial fishing methods

- **Three studies** examined the effects of using hook and line fishing instead of other commercial fishing methods on marine fish populations. One study was in each of the Tasman Sea[1] (Australia), the Atlantic Ocean[2] (Canada) and the Gulf of St. Lawrence[3] (Canada).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled study in the Gulf of St. Lawrence[3] found that fish caught by hook and line methods had greater vitality (an indicator of post-release survival) than fish caught by other gear types.

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (1 study)**: One replicated, controlled study in the Tasman Sea[1] found that using longlines reduced the capture of unwanted small snapper, compared to trawling.
- **Improved size-selectivity of fishing gear (1 study):** One replicated, paired, controlled study in the Atlantic Ocean[2] found that longlining compared to trawling, increased the size selectivity of cod and haddock at larger hook sizes only.

Background

Hook and line fishing involves setting fishing line in the water with baited hooks and is done by hand or using a rod and reel or longlines. In large-scale commercial and offshore fisheries, hook and line fishing usually comprises longline fishing, consisting of a long length of fishing line (up to many kilometres) with multiple branching lines with baited hooks. Longline gear may be set in the water column or on the seabed to target pelagic or demersal species. Hook and line fishing is considered more species- and size-selective than other types of fishing such as trawling (Løkkeborg & Bjordal 1992) and so may capture fewer numbers of non-target species and unwanted smaller fish. In addition, survival of unwanted fish catch may also be higher after capture by hook and line (Sureda *et al*. 2020) and this method of fishing may have little direct impact on the seabed and fish habitats.

Evidence for a related intervention is summarized under *'Alternative harvesting methods - Use an alternative commercial fishing method'*.

Løkkeborg S. & Bjordal Å. (1992) Species and size selectivity in longline fishing: a review. *Fisheries Research*, 13, 311–322.

Sureda A., Barceló C., Tejada S., Montero I., Langley E. & Box A. (2020) Physiological and survival effects of capture of red scorpion fish *Scorpaena scrofa* (Osteichthyes: Scorpaenidae) by different fishing gears in the Balearic Islands (Western Mediterranean). *Fisheries Research*, 229, 105616.

A replicated, controlled study in 1989–1993 at three seabed sites in the Tasman Sea off New South Wales, Australia (1) found that using longlines reduced the capture of unwanted small snapper *Pagrus auratus* compared to using trawls. At all three sites, snapper length caught on longlines was higher than those caught in trawls (longline: 252-317 mm, trawl: 193-266 mm). Overall, 26% of the 274 snapper caught on longlines were under the minimum legal size compared to 89% of 500 snapper caught in trawls.

Trawling and longlining was done at the same three sites at three-month intervals from autumn 1989 to autumn 1993. At each site, three trawl hauls were done with a 42 mm diamond-mesh codend net, towed at 2.5 knots, for 20 minutes. A longline of 33 circle hooks of three different sizes baited with squid was used. At each site, 12 longline deployments were set for 2.5 h. Full gear specifications are detailed in the original paper. The length of all fish was recorded.

A replicated, paired, controlled study in 1991 in two pelagic areas on the central Scotian Shelf in the North Atlantic Ocean off Nova Scotia, Canada (2) found that longlines had a higher or similar size-selectivity for cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* at larger hook sizes only, compared to using trawls. The length at which line-caught cod had a 50% chance of escape (selection length) was 41 cm, 54 cm and 63 cm for three hook sizes, from smallest to largest respectively. The two largest hook sizes were higher than a diamond mesh codend (50 cm), but only the largest hook size was higher than a square mesh codend (56 cm). For haddock, average lengths caught on the two smaller hooks (49–50 cm) were intermediate between those of the diamond and square mesh nets (46–51 cm) and that for the largest hook size was highest (53 cm). Fishing took place in October 1991 using a commercial fishing vessel in depths of 73–123 m. A total of 14,700 circle hooks of three sizes (9.7 mm, 11 mm and 14.7 mm barb length) were deployed on 53 longline sets fished for 6 h. Two otter trawl nets were used: a 130 mm diamond mesh codend and a 130 mm square mesh codend. A small-mesh (40 mm diamond) codend was used to sample the length ranges of fish. Three to seven trawl tows were made each day over 13 days, towed parallel to the set longline gear. The length of captured fish was recorded.

A replicated, controlled study in 2005–2006 of a fished area of seabed in the Gulf of St. Lawrence, Canada (3) found that hook and line gears (longlines and handlines) resulted in greater vitality (indicator of survival potential) of discarded fish in a bottom (groundfish) fishery compared to other fishing gear types. Across all species, the proportion of fish with the highest vitality score (i.e. in overall better condition) was greater in hook and line fisheries (65–95%) compared to trawl and seine gears (10–68%) and gillnets (30%) (see paper for species individual data). Data were collected during the commercial groundfish seasons in 2005 and 2006 (months not reported) in the Gulf of St Lawrence. Four fishing gear types were compared: handlines, bottom-set longlines, mobile bottom gears (trawls and Danish and Scottish seines) and gillnets. Vitality of captured fish was visually assessed and scored (see paper for description of criteria) by observers onboard fishing vessels.

(1) Otway N.M., Craig J.R. & Upston J.M. (1996) Gear-dependent size selection of snapper, *Pagrus auratus*. *Fisheries Research*, 28, 119–132.

(2) Halliday R.G. (2002) A comparison of size selection of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) by bottom longlines and otter trawls. *Fisheries Research*, 57, 63–73.

(3) Benoît H.P., Hurlbut T. & Chassé J. (2010) Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. *Fisheries Research*, 106, 436–447.

Catch, Effort and Capacity Reduction

Evidence for the interventions listed below has been compiled and is currently being summarized. This section will be updated as soon as that is completed.

Limit the number of fishing days
Limit the number of fishing vessels registered in an area or jurisdiction
Limit the number of fishing vessels allowed in an area
Limit the total kilowatt hours fished for towed gears
Limit beam trawl width
Limit the number of dredges per vessel
Limit the number of traps or pots per vessel
Limit the number or length of static nets in an area
Limit vessel engine power capacity
Prohibit certain gear types
Set catch quotas by area
Set catch quotas by species
Set catch quotas by fleet or sector
Introduce catch shares
Establish move-on rules for temporary, targeted closures of part of a fishery when a catch or bycatch threshold is reached/apply real-time closures when a trigger level reached
Introduce fishing permit schemes
Reduce the number of fishing permits granted
Purchase fishing permits from fishers
Purchase fishing vessels from fishers
Eliminate fisheries subsidies that encourage overfishing
Implement vessel decommissioning schemes
Prohibit landing of specific species
Prohibit high-grading in which only the most profitable individuals or species are landed
Implement multi-species management strategies
Use technology to provide real-time quota information and communicate to fishers
Enforce gear and vessel restrictions (e.g. cap engine power, ban gears)
Employ adaptive management methods to achieve long-term goals
Introduce gear exchange programs
Establish gear registration programmes

Protect Reproductive Individuals

2.69 Release fish that are carrying eggs or live young

- We found no studies that evaluated the effects of releasing fish that are carrying eggs or live young on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear contacting the seabed. Removing fish that are carrying/brooding eggs (females or males) or live young (such as many sharks) not only kills the adult but prevents successful spawning or rearing of the young and limits the overall reproductive potential of the population. Releasing fish with eggs or live young may help sustain fish populations and protect the hatching or rearing of young fish.

2.70 Release males of species known to guard nests during breeding season

- We found no studies that evaluated the effects of releasing males that guard nests during the breeding season on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear contacting the seabed. Removal of male fish known to guard nests or protect their young during the breeding season not only kills the adult but may prevent successful spawning or rearing of the young and limit the overall reproductive potential of the population. Examples include black bream *Spondyliosoma cantharus* (Pinder *et al*. 2017) and lingcod *Ophiodon elongatus* (Withler *et al*. 2004). Releasing male fish of these species during breeding may help reduce fishing pressure and the effects of overexploitation and protect the hatching or rearing of young fish.

Pinder A.C., Velterop R., Cooke S.J. & Britton J.R. (2017) Consequences of catch-and-release angling for black bream *Spondyliosoma cantharus*, during the parental care period: implications for management. *ICES Journal of Marine Science*, 74, 254–262.

Withler R.E., King J.R., Marliave J.B., Beaith B., Li S., Supernault K.J. & Miller K.M. (2004) Polygamous mating and high levels of genetic variation in lingcod, *Ophiodon elongatus*, of the Strait of Georgia, British Columbia. *Environmental Biology of Fishes*, 69, 345–357.

2.71 Set a minimum landing size for commercially fished species

- **Four studies** examined the effects of setting a minimum landing size for commercially fished species on marine fish populations. One study was a global review[1] and one study was in each of the Tasman Sea[2] (Australia), the Baltic Sea[3] (Northern Europe) and the Ionian Sea[4] (Greece).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Reproductive success (2 studies):** One global review[1] reported that one of five swordfish fisheries showed an increase in swordfish recruitment after the setting of recommended minimum landing sizes and catch limits, with recruitment in the other fisheries either highly variable or unable to be assessed. A replicated study in the Ionian Sea[4] reported that, despite established minimum sizes, most fish landed in commercial catches were immature, and thus had never spawned.

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of unwanted catch (1 study):** Two before-and-after studies (one replicated) in the Tasman Sea[2] and Baltic Sea[3] found that following an increase in the set minimum landing size there was no reduction in the catches of discarded dusky flathead[2] and Atlantic cod[3], and discarding of flathead increased in one of three cases[2].

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear contacting the seabed. Removal of small fish before they have matured and had an opportunity to reproduce limits the overall reproductive potential of the population and can cause severe depletions. The minimum landing size is the smallest fish measurement (usually total length) at which it is legal to retain a fish and is dependent on species (e.g. size at maturity) and sea region. Setting a minimum size at which fish can be landed may help ensure that fish grow to a size that gives them the opportunity to spawn at least once, thus helping to maintain the population. However, to ensure that discarding of fish below a given minimum size is minimized, the size-selectivity of the fishing gear may also need to be improved to better match the size limit.

For similar interventions, see *'Protect Reproductive Individuals - Set a maximum landing size for commercially fished species'* and *'Specify a size range of capture for commercially fished species'*.

A review in 2000 of broadbill swordfish *Xiphias gladius* fisheries worldwide (1) reported that after recommended minimum landing sizes and catch limits were introduced, strong recruitment was found for one stock, whilst four others could not be assessed. This result was not tested for statistical significance. After measures were introduced in 1994, recruitment of age-1 swordfish in the North Atlantic area was strong in 1997 and in 1998 (no data reported), while in the four other areas there were either wide fluctuations in recruitment or there was no reliable assessment of the stocks (see paper for details). In addition, compliance was generally poor and between 19–37% of swordfish landed from various countries fishing in the Atlantic in 1998 were under the recommended size (125 cm). In 1994, minimum size limits and total allowable catches for swordfish were recommended by the International Commission for the Conservation of Atlantic Tunas. However, the recommendations were enforced by some, but not all member states, and following the limits some vessels relocated to other regions and an increase in discarded swordfish was reported. Five swordfish fisheries were reviewed to develop guidelines for the assessment and management of developing swordfish fisheries.

A replicated, before-and-after study in 2001 of three estuaries in the Tasman Sea, Australia (2) found that the effect of an increase in the minimum landing size for dusky flathead *Platycephalus fuscus* varied between estuaries, and there was an increase in the amount of discarded (undersized) flathead in gillnets in one of three estuaries. Catch rate of undersized dusky flathead was similar in the period after the increase in minimum size compared to before in two of the three estuaries (after: 0.05–0.14 fish/100 m, before: 0.04–0.16 fish/100 m) and was higher after in the other (after: 0.46 fish/100 m, before: 0.04 fish/100 m). In addition, no difference was seen in catch rates of commercial-sized flathead across all estuaries (after: 2.6–4.6 fish/100 m net, before: 4.1–4.8 fish/100 m net). Minimum landing size of dusky flathead was increased from 33 cm to 36 cm on 1st July 2001. A total of 81 commercial gillnet catches targeting flathead were sampled by scientific observers before and after the change in minimum size: in February-June and July-November in two estuaries (Wallis Lake and Tuggerah Lake), and in May-June and July-August in another estuary (Lake Illawarra), all in New South Wales. All species caught were identified, counted and the total weight recorded.

A before-and-after study in 2002–2003 in a heavily fished area of seabed in the Baltic Sea, Northern Europe (3) found that an increase in minimum landing size did not reduce the amount of Atlantic cod *Gadus morhua* discarded by the trawl fishery for this species. This result was not tested for statistical significance. In the year following the minimum landing size increase in 2003 the discard rate of cod was 0.23 (rate by fish numbers) and 0.14 (rate by fish weight). In the year before the increase the discard rate was 0.18 by number and 0.09 by weight. The minimum landing size of Baltic cod was increased from 35 cm to 38 cm in January 2003. However, in April 2003, high discarding led to the temporary closure of the trawl fishery in Baltic European Union waters. Measures to improve selectivity of fishing gear in line with the increased minimum landing size were implemented in September 2003 (see paper for details). The typical trawl configuration in use at the time of the intervention was a 130 mm diamond-mesh codend. Discard data was collected from the Swedish cod fishing fleet by on-board observers.

A replicated study in 2004–2005 of fishing grounds in the Ionian Sea, Greece (4) found that the minimum landing sizes set for 13 fish species were smaller than their estimated lengths of maturity and in commercial landings over 50% of fish were immature, indicating that minimum sizes did not prevent most fish from being caught before they had a chance to spawn even once. These results were not tested statistically. For 13 fish species, the minimum landing sizes (total length) in use were between 2–38 cm smaller than the estimated size at which 50% of fish of a given species become mature (see paper for species individual data). The average percentage of immature individuals landed (smaller than the 50% maturity size) was greater than half of the catch for all gear types (55–92%). In addition, the average percentage of fish landed with lengths smaller than the minimum size varied between gear types and the overall average (all species) ranged from 6% (longlines) to 43% (beach seines). Data were collected from the landings of 22 vessels fishing out of Zakynthos Island between July 2004–2005. Total length of all fish was measured from landings by five gear types: trawls (11 trips), purse seines (27 trips), beach seines (3 trips), trammel nets (111 trips) and longlines (34 trips).

(1) Ward P., Porter J.M. & Elscot S. (2000) Broadbill swordfish: status of established fisheries and lessons for developing fisheries. *Fish and Fisheries,* 1, 317–336.

(2) Gray C.A., Johnson D.D., Young D.J. & Broadhurst M.K. (2004) Discards from the commercial gillnet fishery for dusky flathead, *Platycephalus fuscus*, in New South Wales, Australia: spatial variability and initial effects of change in minimum legal length of target species. *Fisheries Management and Ecology*, 11, 323–333.

(3) Suuronen P., Tschernij V., Jounela P., Valentinsson D. & Larsson P-O. (2007) Factors affecting rule compliance with mesh size regulations in the Baltic cod trawl fishery. *ICES Journal of Marine Science*, 64, 1603–1606.

(4) Stergiou K.I., Moutopoulos D.K. & Armenis G. (2009) Perish legally and ecologically: the ineffectiveness of the minimum landing sizes in the Mediterranean Sea. *Fisheries Management and Ecology*, 16, 368–375.

2.72 Set a maximum landing size for commercially fished species

- We found no studies that evaluated the effects of setting a maximum landing size for commercially fished species on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear contacting the seabed. For many fish species the reproductive potential (e.g. the annual numbers of eggs/young produced by the females) increases with size and/or age. Removal of the larger fish from a population thus reduces the overall reproductive potential and may also apply a genetic selection pressure that favours fish that mature at a smaller size that may continue breeding (Borrell 2013). Setting a maximum landing size (i.e. the largest fish measurement – usually total length – at which it is legal to retain a fish) may protect the largest fish with the highest reproductive potential, thus helping to maintain the population.

For similar interventions, see *'Protect Reproductive Individuals - Set a minimum landing size for commercially fished species'* and *'Specify a size range of capture for commercially fished species'*.

Borrell B. (2013) Ocean conservation: A big fight over little fish. *Nature*, 493, 597–598.

2.73 Specify a size range of capture for commercially fished species

- We found no studies that evaluated the effects of specifying a size range of commercially retained fish species on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear contacting the seabed. Removal of the smaller or larger sizes of fish from a population reduces the overall reproductive potential by killing either the immature fish before they have reached maturity or the larger fish that produce the highest numbers of eggs. Setting specific fish size ranges that allow harvesting of intermediate sizes may help protect the overall reproductive potential by avoiding fishing mortality of the smallest and largest individuals.

For similar interventions, see *'Protect Reproductive Individuals - Set a minimum landing size for commercially fished species'* and *'Set a maximum landing size for commercially fished species'*.

2.74 Protect spawning fish from capture

- **Four studies** examined the effects of protecting spawning fish on marine fish populations. Two studies were in the North Atlantic Ocean[1,3] (Canada, UK) and one study was in each of the Philippine Sea[2] (Palau) and the Tasman Sea[4] (Australia).

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One before-and-after, site comparison study in the Atlantic Ocean[3] found no increase in the biomass of the spawning stock of Atlantic cod in the nine years following implementation of a seasonal fishery closure to protect spawning cod, compared to fished areas.
- **Survival (1 study):** One before-and-after, site comparison study in the Atlantic Ocean[3] found no change in Atlantic cod survival in the nine years after a seasonal fishery closure to protect spawning cod was implemented, compared to fished areas.
- **Condition (1 study)**: One before-and-after, site comparison study in the Atlantic Ocean[3] found no change in the length composition of Atlantic cod in the nine years following a seasonal fishery closure to protect spawning cod, compared to fished areas.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One site comparison study and one study in the Northeast Atlantic Ocean[1] and Tasman Sea[4] reported that spawning areas closed seasonally or permanently to fishing were used by tagged adult Atlantic cod for nearly a third of time during spawning[1], and by school sharks less than one year old for up to 80% of time, but by school sharks between one and two years old for 18% of time, compared to areas outside.

OTHER (2 STUDIES)

- **Commercial catch abundance (2 studies):** One before-and-after, site comparison study in the Atlantic Ocean[3] found no change over nine years in commercial catches of Atlantic cod following a seasonal fishery closure to protect spawning cod compared to fished areas. One replicated, controlled study in the Philippine Sea[2] found that during seasonal closure of a grouper fishery to protect spawning individuals, the commercial catch numbers of other fish groups (herbivores) increased, indicating they were being targeted more by spear fishers compared to the open season.

Background

Fishing can impact marine fish through species removal or habitat damage from fishing gear contacting the seabed. Many fish species are known to aggregate into denser groups of individuals during specific times to reproduce (spawn) or during early development (nursery areas). The groups may be made up exclusively of fish of one sex and/or stage of maturity. The months during which spawning activity takes place differs between species and areas and the onset is normally dependent on water temperatures. But for any given species/area the overall timing of these periods can be relatively stable between years. As well as taking place at regular times, spawning activity may also take place at the same sites each year, making their occurrence more easily predicted. In the same way nursery habitats used by groups of very young fish are often identifiable. Protecting known spawning or nursing individuals by prohibiting or limiting fishing activity may reduce fishing mortality during highly sensitive periods and allow reproduction or early development to take place with minimal disturbance.

Evidence for a similar intervention relating to the protection of spawning activity is summarized under *'Spatial and Temporal Management - Establish temporary fishery closures'*.

A study in 2007–2012 of a seabed area in the Gulf of St. Lawrence, Northeast Atlantic Ocean, Canada (1) found that tagged adult Atlantic cod *Gadus morhua* showed frequent and long-term use over five years of a seasonally closed area designed to protect a cod spawning aggregation from fishing mortality. These results were not statistically tested. Tagged adult cod spent an average 28% of time (range 0–72%) inside the closed area during its enforcement period and were recaptured after between 224–746 days, indicating long-term survival. Movement patterns of different groups of cod indicated that migratory cod used the area more extensively (13–72%) than non-migratory cod (0%). In addition, 17 tags from the 353 adult cod tagged were returned (i.e. captured; the fate of the other 336 is unknown). A closed area of 5,000 km^2 was implemented in 2002 prohibiting all ground fishing activities yearly from April 1st to June 15th. Between 2007–2012, a total of 353 cod were captured using baited handlines and surgically implanted with data storage tags. Of the 17 tags returned, complete data from 14 were used to reconstruct cod movements.

A replicated, controlled study in 2009 of reef fisheries in the Philippine Sea, Palau, Micronesia (2) found that the implementation of a closed season to protect spawning aggregations of five grouper species *Serranidae* spp. resulted in higher spear fisher catch rates of other fish species (herbivores) by number but not by weight, compared to the open season, and indicated an increase in the commercial targeting of these species. Average catch numbers of herbivorous fish actively targeted by spear fishers throughout the year were higher during the closed grouper season (7 fish/person/h) than the open season (4 fish/fisher/h), but there was no difference in catch rates by weight (closed: 4, open: 3 kg/fisher/h). For other groups of herbivorous fish (harvested opportunistically or normally avoided), catch rates were higher during the closed season by both number (closed: 2.2, open: 0.6 fish/fisher/h) and weight (closed: 1.6, open: 0.5 kg/fisher/h). Since 1994, a closed season (April–July) for five grouper species was implemented to protect spawning fish. In 2009, daily surveys of reef fish landings were done at Koror fish market for two weeks during the open (18–31st March) and closed (13–26th July) grouper fishing seasons. Nineteen spear fisher catches during the closed season and 23 during the open season were sampled and ranked by category of herbivorous fish based on information given by the fishers: actively targeted (10 species), opportunistically harvested (24 species) and avoided (17 species). Species, weight and length was recorded for parrotfishes *Scaridae*, surgeonfishes and unicornfishes *Acanthuridae* and rabbitfishes *Siganidae*.

A before-and-after, site comparison study in 1986–2010 of an area of seabed in the north east Atlantic Ocean, western Scotland, UK (3) found that a seasonal fishery closure implemented to protect the spawning of Atlantic cod *Gadus morhua* resulted in no change in catches, spawning stock biomass, length composition or mortality of cod in the nine years following implementation compared to before and to two fished areas. Data were reported as statistical model results. Catch/unit effort and spawning stock biomass of cod decreased after the seasonal closure was implemented, in both the closed area and two fished areas. The length composition of cod was similar between the closed and fished areas and did not change after the closure. Mortality rates differed between areas before and after the closure and intermediate mortality rates were found in the closed area compared to the two fished areas. Annual seasonal fishery closures from 6th March to 30th April were introduced in the Firth of Clyde in 2001 to protect spawning Atlantic cod. Cod were surveyed in one of two zones of the closure area, both closed to gears that target fish but permitted creeling and scallop dredging. Trawling for Norway lobster *Nephrops* was allowed in the surveyed zone but not in the adjacent zone (not surveyed). Cod landings and hours fished by vessels over 10 m along the west coast of Scotland were extracted from the Marine Scotland database. Cod data from within the closure and from two fished reference areas were obtained from scientific bottom trawl surveys for the period 1986–2010.

A site comparison study in 2012–2013 in a coastal bay in the Tasman Sea off Tasmania, Australia (4) found that tagged school sharks *Galeorhinus galeus* less than one year old were detected more frequently inside than outside a shark spawning and nursery ground in which the taking of sharks was prohibited (shark refuge area), however slightly older immature sharks did not tend to stay within the refuge. These results were not statistically tested. On average, the 31 tagged sharks less than one year old were detected for 80% of time inside the closed refuge area. Of these, 19 sharks did not leave the refuge throughout the study, nine periodically left and returned between May and September 2012 and three left and were not detected again. Older immature sharks (between one and two years) spent on average 18% of time inside the refuge area and all eight individuals left the refuge in autumn and only one returned the following spring. Data were collected from 39 electronically tagged sharks. Shark movements were tracked by

58 receivers deployed in and around a shark refuge area (targeting or taking of sharks prohibited year round, year established not given) and 66 receivers in two areas further up the east coast of Tasmania. Data were recorded from January 2012 until May 2013.

(1) Le Bris A., Fréchet A. & Wroblewski J.S. (2013) Supplementing electronic tagging with conventional tagging to redesign fishery closed areas. *Fisheries Research*, 148, 106–116.
(2) Bejarano Chavarro S., Mumby P.J., Golbuu Y. (2014) Changes in the spear fishery of herbivores associated with closed grouper season in Palau, Micronesia. *Animal Conservation*, 17, 133–143.
(3) Clarke J., Bailey D.M. & Wright P.J. (2015) Evaluating the effectiveness of a seasonal spawning area closure. *ICES Journal of Marine Science*, 72, 2627–2637.
(4) McAllister J.D., Barnett A., Lyle J.M. & Semmens J.M. (2015) Examining the functional role of current area closures used for the conservation of an overexploited and highly mobile fishery species. *ICES Journal of Marine Science*, 72, 2234–2244.

Enforcement and Compliance to Reduce Illegal Fishing

2.75 Deploy patrol boats

- We found no studies that evaluated the effects of deploying patrol boats on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws. Compliance with these measures is important to protect commercially targeted and non-targeted species and their habitats: non-compliance has been shown to have a negative impact on the biomass of targeted species in no-take marine reserves (Bergseth *et al*. 2015). One way to enforce compliance is to deploy dedicated fisheries patrol boats. Fisheries enforcement patrols have the powers to board vessels to inspect for non-compliance and any illegal activity and heavy financial penalties can be issued. These may act as deterrents to fishers and help prevent attempts at illegal fishing altogether. The fish resource and habitats may thus be sustained or conserved by ensuring that the aims of management regulations have the best chance of being met.

Bergseth B.J., Russ G.R. & Cinner J.E. (2015) Measuring and monitoring compliance in no-take marine reserves. *Fish and Fisheries*, 16, 240–258.

2.76 Organise vessel monitoring systems

- We found no studies that evaluated the effects of organising monitoring systems on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws. Some however may have no regulation and fishing activity takes place unchecked with unknown consequences to marine fish populations. In response to increased illegal, unreported and unregulated fishing activity towards the end of the 20th century, ways to regulate and monitor fishing vessel activity were established (Dunn *et al*. 2015). These included catch documentation schemes and international surveillance networks. More recently, electronic vessel monitoring systems, such as satellite, drones or even drifting fish attraction devices (Toonen & Bush 2020) have been developed to track fishing activity. As well as being able to help detect and subsequently prevent illegal fishing activity, monitoring systems may also provide unbiased information on the patterns of fisheries activity on annual and seasonal scales. Such data can be used to inform fisheries management plans to help enhance conservation and biodiversity objectives.

Dunn D.C., Jablonicky C., Crespo G.O., McCauley D.J., Kroodsma D.A., Boerder K., Gjerde K.M. & Halpin P.N. (2018) Empowering high seas governance with satellite vessel tracking data. *Fish and Fisheries*, 19, 729–739.

Toonen H.M & Bush S.R. (2020) The digital frontiers of fisheries governance: fish attraction devices, drones and satellites. *Journal of Environmental Policy and Planning*, 22, 125–137.

2.77 Use human observers onboard fishing vessels to monitor catches and discards

- We found no studies that evaluated the effects of using human observers onboard fishing vessels to monitor catches and discards on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often managed by a series of technical or spatial measures that aim to ensure the sustainable harvest of an important food resource whilst conserving and enhancing the marine environment. The success of such management plans relies on compliance with the regulations as well as accurate information on commercial and non-target catches and fishing effort, as well as discards and the operational characteristics of fisheries. One way to encourage compliance and at the same time provide useful unbiased data may be to use trained scientific observers onboard commercial vessels to record the details of catches and fishing deployments. Onboard human observation can document and interpret many at-sea activities that other monitoring systems are unable to provide, for example, catch composition, discarding activity, bycatch handling and determining bycatch condition and fate on release (Ewell *et al.* 2020). This may ultimately help ensure better compliance and management of the fisheries and improved protection of fish habitats.

For a similar intervention relating to onboard monitoring of catches, see *'Enforcement and Compliance to Reduce Illegal Fishing - Use onboard CCTV for monitoring catches and discards'*.

Ewell C., Hocevar J., Mitchell E. Snowden S. & Jacquet (2020) An evaluation of Regional Fisheries Management Organization at-sea compliance monitoring and observer programs. *Marine Policy*, 115, 103842.

2.78 Use citizen surveillance to report illegal fishing

- We found no studies that evaluated the effects of using citizen surveillance to report illegal fishing on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws. Compliance with these measures is important to protect commercially targeted and non-targeted species and their habitats: non-compliance has been shown to have a negative impact on the biomass of targeted species in no-take marine reserves (Bergseth *et al*. 2015). One way to improve compliance and help enforce regulations may be to ask citizens/the wider public (as opposed to government/state or scientific organisations) to provide surveillance or information on fishing activity. In practice, this may be via the provision of a dedicated system for reporting illegal activity (e.g. a telephone hotline).

Bergseth B.J., Russ G.R. & Cinner J.E. (2015) Measuring and monitoring compliance in no-take marine reserves. *Fish and Fisheries*, 16, 240–258.

2.79 Enforce port controls

- We found no studies that evaluated the effects of enforcing port controls on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws that control what can be caught, where and how much. However, regulations also extend to the landing and recording of catches at ports. Port fisheries controls include limiting the numbers of ports where commercial fishers can land sensitive species or large volumes of fish (sometimes termed as "designated ports") making it easier to control and accurately record such catches and landings. Other port controls include monitoring licensed vessels and their landings for undersized or illegal fish, and authorisation of documentation to verify or validate landings for ongoing sale or export. Effective enforcement of port controls may act as a deterrent to prevent illegal fishing by making it more difficult to land and sell illegal fish thus helping to protect fish populations from the threat of overexploitation.

2.80 Use onboard CCTV for monitoring catches and discards

- We found no studies that evaluated the effects of using onboard CCTV monitoring on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws. Compliance with these measures is important to protect commercially targeted and non-targeted species and their habitats: non-compliance has been shown to have a negative impact on the biomass of targeted species in no-take marine reserves (Bergseth *et al*. 2015). One way to improve compliance may be to use onboard camera equipment such as CCTV to monitor and record catches and discarding that is subsequently analysed and enforced by management organisations ashore. This may encourage fishers to make more effort to avoid catching prohibited or undersized fish (if, for example, they are regulated) and may reduce fishing mortality (Course *et al*. 2011).

For a similar intervention relating to onboard monitoring of catches, see *'Enforcement and Compliance to Reduce Illegal Fishing - Use human observers onboard fishing vessels to monitor catches and discards'*.

Bergseth B.J., Russ G.R. & Cinner J.E. (2015) Measuring and monitoring compliance in no-take marine reserves. *Fish and Fisheries*, 16, 240–258.

Course G., Pasco G., Revill A. & Catchpole T. (2011) The English North Sea Catch-Quota pilot scheme-Using REM as a verification tool. Cefas, UK, 44pp.

2.81 Use flags to signal the legal nationality of a fishing vessel

- We found no studies that evaluated the effects of using a flag to identify the legal nationality of a fishing vessel on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

When a fishing vessel is registered, it means that the vessel has the nationality of the country and can fly the flag of that country. This is called the law of the flag. The registered country is often referred to as the flag state and as such has exclusive legal jurisdiction over its vessels in international waters. Vessels can be without nationality, (often called stateless, flagless, or unregistered vessels) but they undermine the law of the flag regime because no state can exercise control over them. Being able to openly identify the registered state or nationality of vessels that, for instance, are suspected to be engaging in illegal fishing activity or otherwise contributing to overexploitation, may help to prevent these activities by allowing the flag state or other states to take enforcement action to deal with the threat.

For a similar intervention relating to the use of the flag on marine vessels, see *'Enforcement and Compliance to Reduce Illegal Fishing - Eliminate flags of convenience'*.

2.82 Eliminate flags of convenience

- We found no studies that evaluated the effects of eliminating flags of convenience on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing vessel owners are required to register or licence their vessel in a country and it is subsequently deemed the nationality of the vessel, falling under the laws and jurisdiction of that country. This is called its "flag state" (see '*Enforcement and Compliance to Reduce Illegal Fishing - Use flags to signal the legal nationality of a fishing vessel'*). A flag of convenience is a business practice whereby a vessel is registered in a country other than that of the vessel's owner. Adopting a flag of convenience can make it easier to engage in illegal, unreported and unregulated fishing activity (Gianni & Simpson 2005). Elimination of flags of convenience may thus help prevent illegal fishing and protect fish populations and marine environments from the threat of over exploitation.

Evidence for a related intervention describing the use of the flag on marine vessels is summarized under *'Enforcement and Compliance to Reduce Illegal Fishing - Use flags to signal the legal nationality of a fishing vessel'*.

Gianni M. & Simpson W. (2005) The Changing Nature of High Seas Fishing: how flags of convenience provide cover for illegal, unreported and unregulated fishing. Australian Department of Agriculture, Fisheries and Forestry.

2.83 Establish open and transparent reporting of fishing effort data

- We found no studies that evaluated the effects of establishing open and transparent fishing effort data on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws. Effective management relies on accurate information on fishing activity and the level of compliance. One way to encourage compliance and to increase enforcement may be to require commercial fishers to provide detailed information on their fishing operations, including the amount of time spent fishing, catches and landings, to the relevant fisheries administrations. Many countries already have in place schemes to enable catch data reporting (e.g. logbooks) and publish annual fishing effort data that is increasingly freely accessible via the worldwide web. Some countries (e.g. Brazil) have developed online logbooks to increase transparency in reporting compared to paper logbooks that are not widely accessible.

2.84 Use methods to trace the source of catch

- We found no studies that evaluated the effects of using methods to trace the sources of catches on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Across the globe fish stocks are at risk of collapsing due to overexploitation and a factor that contributes to the problem is illegal fishing. Using methods to trace the source of catches should provide the transparency and openness required to confirm and validate legal fish catches. This may deter or prevent illegal fishing if fishers know they may be caught if they try to land illegally caught fish. One such method is DNA testing that can differentiate fish populations of the same species from where they were caught. That means telling, for instance, the difference between Atlantic cod captured legally in the Eastern Baltic and cod caught illegally in the North Sea. Or it can mean identifying prohibited or endangered species such as sharks (Feitosa *et al*. 2018).

Feitosa L.M, Martins A.P.B, Giarrizzo T., Macedo M., Monteiro I.L, Gemaque R., Nunes J.L.S., Gomes F., Schneider H., Sampaio I., Souza R., Sales J.B., Rodrigues-Filho L.F., Tchaicka L. & Carvalho-Costa L.F. (2018) DNA-based identification reveals illegal trade of threatened shark species in a global elasmobranch conservation hotspot. *Scientific Reports*, 8, article 3347.

2.85 Issue high fines and penalties for non-compliance with fisheries regulations

- We found no studies that evaluated the effects of issuing high fines and penalties for non-compliance with fisheries regulations on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine fisheries throughout the world are often highly regulated and may be subject to many different international or national laws and byelaws that control what can be caught or landed, where and how much. Illegal, unreported and unregulated fishing activity is a huge threat worldwide and those engaging in criminal activity on a large scale may gain substantially financially. Heavy fines or penalties may act as a deterrent to prevent illegal fishing or non-compliance and help protect fish populations from the effects of overfishing.

2.86 License fish buyers

- We found no studies that evaluated the effects of licensing fish buyers on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Non-compliance of fisheries regulations is a common occurrence and illegal, unreported and unregulated fishing activity is a huge threat to fish populations worldwide. The licensing of fish buyers may act as a deterrent to help prevent the buying and selling of illegal catches of fish and thus may help to mitigate the effects of overfishing and conserve fish populations.

Stakeholder Engagement and Behaviour Change

2.87 Involve fishers and stakeholders in co-management

- **Two studies** examined the effect of involving fishers and stakeholders in co-management on marine fish populations. One study was in the South China Sea[1] (Vietnam) and the other was in the Pacific Ocean[2] (Tonga).

COMMUNITY RESPONSE (1 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Reduction of fishing effort (1 study):** One before-and-after study in the Pacific Ocean[2] found that in the five years after implementation of a new co-management system there was no decrease in overall fishing effort in the managed area.
- **Commercial catch abundance (1 study):** One before-and-after study in the Pacific Ocean[2] found no increase in total fish catch rates and a decrease in catch rates of half of the six species groups individually inside an area with a new co-management system after five years.
- **Improved compliance/reduction of illegal fishing activity (1 study):** One before-and-after study in the South China Sea[1] reported that after co-management was established in an area there was a decrease in illegal fishing using destructive fishing gears.

Background

Co-management can be defined as a partnership arrangement in which local stakeholders such as fishers or tourist organisations share the responsibility and authority for the management of resources with national or local state bodies. This type of management is thought to be more effective as the stakeholders often have local knowledge and are involved in the decision making and management of the resource (Pomeroy & Rivera 2006). This gives stakeholders a platform to express their views and may lead to improved compliance or uptake of new management plans.

Pomeroy R.S & Rivera-Guieb R. (2006) Fishery Co-Management: A Practical Handbook. CABI Publishing and International Development Research Centre, Wallingford, UK.

A before-and-after study in 2012–2014 of three areas of the Tam Giang Lagoon in the South China Sea, Vietnam (1) reported that after the implementation of co-management and territorial rights for fishing, there was a reduction in the number of fishers engaged in illegal activity using destructive fishing gears compared to before. Results were not statistically tested. In all six survey areas and in all but one case, the numbers of violators using destructive fishing gears (such as electric shock and bottom trawls) from both within and outside the lagoon communities were reported to be lower after implementation of co-management (after: maximum of 10 persons and up to 8 boats/day, before: maximum of 50 persons and 15 boats/day). See original paper for data by individual area and violator origin. Co-management was progressively established in the Tam Giang lagoon system (two thirds – 13,860 ha – allocated as co-managed, rest open access) since 2002, resulting in 64 fishery associations, 34 of which also had territorial rights for fishing (first one established 2009). Data were collected between late 2012 to 2014 from surveys of six fishing communities (two each in the north, central and south lagoon areas, 252 randomly selected members of associations), supplementary interviews and focus groups with resource managers and practitioners. Survey respondents were asked whether or not there were changes to a number of social and ecological measures before and after 2009 (selected because the first territorial rights were allocated and all associations established for at least one year).

A before-and-after study in 2007–2011 of reef and lagoon areas of an inhabited coral reef island in the Pacific Ocean, Tonga (2) found that under a new co-management system with territorial fishing rights (exclusion of fishers from outside areas), total fish catch rates did not increase in the five years following implementation, catch rates of half of the six individual species groups decreased and there was no decrease in overall fishing effort. No differences in total fish catch rates and catch rates of three of six fish groups (*Acanthuridae - Naso spp*., *Holocentridae*, *Lethrinidae*) were found since implementation, but catch rates of the remaining three (*Acanthuridae - Acanthurus spp., Scaridae, Serranidae*) decreased (data reported as statistical results). In addition, no difference in overall fishing effort was found (data reported as statistical results), but the authors reported that this was likely to be due to reduced travel to fishing grounds further away by resident fishers with the new exclusive rights. Co-management formally commenced on the island of 'O'ua (one of 170 Tongan Islands) in 2007, covering a marine area of 4,606 ha, of which 203 ha was a no-take zone. Only residents on 'O'ua could fish the co-managed area, whereas before, there was access also to fishers from neighbouring islands and small commercial vessels from the main island group. Fish catch landings (species and weight/trip) were sampled each year between 2007–2011 (total 184 records), collected opportunistically from individual fishers (see original paper for fishing types). Catch data from spearfishing only was used for statistical analysis.

(1) Ho N.T.T., Ross H. & Coutts J. (2016) Evaluation of social and ecological outcomes of fisheries co-management in Tam Giang Lagoon, Vietnam. *Fisheries Research*, 174, 151–159.
(2) Webster F.J., Cohen P.J., Malimali S., Tauati M., Vidler K., Mailau S., Vaipunu L. & Fatongiatau V. (2017) Detecting fisheries trends in a co-managed area in the Kingdom of Tonga. *Fisheries Research*, 186, 168–176.

2.88 Include fishers in management groups for marine protected areas

- We found no studies that evaluated the effects of including fishers in management fora for marine protected areas on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Marine Protected Areas are designations to protect and conserve areas based on a particular ecological feature or sensitivity. The level of restrictions on human activities, including fishing, within such areas varies. Some areas have multiple users and may previously have been a source of food and income for fishers. Including fishers in the groups that set out the design and management of protected areas may improve compliance and help to create more effective management zones (Weigel *et al*. 2014)

Weigel J., Mannle K.O., Bennett N.J., Carter E., Westlund L., Burgener V., Hoffman Z., Da Silva A.S., Kane E.A., Sanders J., Piante C., Wagiman S. & Hellman A. (2014) Marine protected areas and fisheries: bridging the divide. *Aquatic Conservation*, 24, 199–215.

2.89 Involve fishers in designing and trialling new gear types to encourage uptake of more selective fishing gear

- We found no studies that evaluated the effects of involving fishers in designing and trialling new gear types on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

One of the core aims of any management plan to sustainably harvest the marine fish resource is to only remove specific sizes or species, thereby minimizing unwanted catch and mortality. This can partly be achieved by making fishing gear as selective as possible. Fishers have knowledge and information about the marine environment that may be invaluable in informing the design and potential uptake of new fishing gear. Fishers are unlikely to use new gear that is impractical to handle and deploy or that causes large losses of their commercial target catch. Involving fishers in the process may not only help encourage development of more selective fishing gears, but it may ensure more successful uptake if the potential solutions have fisher buy-in and approval (Eliasen *et al.* 2019; Feekings *et al*. 2019).

Eliasen S.Q., Feekings J., Krag L., Veiga–Malta T., Mortensen L.O. & Ulrich C. (2019) The landing obligation calls for a more flexible technical gear regulation in EU waters - Greater industry involvement could support development of gear modifications. *Marine* Policy, 99, 173–180.

Feekings J., O'Neill F.G., Krag L., Ulrich C. & Malta T.V. (2019) An evaluation of European initiatives established to encourage industry-led development of selective fishing gears. *Fisheries Management and Ecology*, 26, 650–660.

2.90 Introduce economic incentives to encourage sustainable fishing

- We found no studies that evaluated the effects of introducing economic incentives to encourage sustainable fishing on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Sustainable fishing practices limit harvest levels to prevent overfishing and help reduce unwanted catch. However, for fishers, fishing more sustainably may involve changing to a more selective fishing gear or a reduction in catch quantities, both of which incur economic outlay or loss. Economic incentives to use or change to more sustainable practices, and thus reduce the effects of overfishing, may encourage uptake by helping to offset economic losses (Costello *et al*. 2010).

Costello C., Lynham J., Lester S.E. & Gaines S.D. (2010) Economic incentives and global fisheries sustainability. *Annual Review of Resource Economics*, 2, 299–318.

2.91 Involve stakeholders in allocation of harvest rights

- We found no studies that evaluated the effects of involving stakeholders in the allocation of harvest rights on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Harvest rights can be used to allocate fishing licences or quotas to individuals or entities. Using this system can ensure that fish stocks are not overexploited. Involving fishers and other stakeholders in the allocation process may reduce conflict and encourage compliance by users of the marine fish resource (Smith *et al.* 2019).

Smith S.L., Battista W., Sarto N., Fujita R., Stetten D.C., Karasik R. & Burden M. (2019) A framework for allocating fishing rights in small-scale fisheries. *Ocean & Coastal Management*, 177, 52–63.

2.92 Engage stakeholders/fishers in scientific research and data collection

- We found no studies that evaluated the effects of engaging fishers in scientific data collection on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Engagement and agreement of stakeholders and fishers in scientific research and data collection is believed to be essential for shared problem solving and ultimately for any management plan to succeed (Mackinson *et al.* 2011). Engaging fishers to collect scientific data may improve the coverage of data and help give fishers a better understanding of the information underpinning management plans. This in turn may improve compliance and buy-in to proposals and help reduce the impacts of fishing.

Mackinson S., Wilson D. C., Galiay P. & Deas B. (2011) Engaging stakeholders in fisheries and marine research. *Marine Policy*, 35, 18–24.

2.93 Promote knowledge exchange between fishers to improve good practice

- We found no studies that evaluated the effects of promoting knowledge exchange between fishers to improve good practice on marine fish populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishers commonly share information through social relationships, and this may lead to increased fishing success (Turner *et al*. 2014). However, knowledge exchange between fishers could also be used as a tool to help promote sustainable practices, particularly if the central fishers in information-sharing networks can be identified and co-opted to assist managers in the spreading of conservation information (Mbaru & Barnes 2017).

Mbaru E.K. & Barnes M.L. (2017) Key players in conservation diffusion: Using social network analysis to identify critical injection points. *Biological Conservation*, 210, 222–232.

Turner R.A.; Polunin N.V.C. & Stead S.M. (2014) Social networks and fishers' behavior: Exploring the links between information flow and fishing success in the Northumberland lobster fishery. *Ecology and Society,* 19, 38.

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Afonso A.S., Santiago R., Hazin H. & Hazin F.H.V. (2012) Shark bycatch and mortality and hook bite-offs in pelagic longlines: Interactions between hook types and leader materials. *Fisheries Research*, 131–133, 9–14. *

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Alemany D., Iribarne O.O. & Acha E.M. (2013) Effects of a large-scale and offshore marine protected area on the demersal fish assemblage in the Southwest Atlantic. *ICES Journal of Marine Science*, 70, 123–134. *

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Andrew N.L., Kennelly S.J. & Broadhurst M.K. (1993) An application of the Morrison soft TED to the offshore prawn fishery in New South Wales, Australia. *Fisheries Research*, 16, 101–111. *

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Broadhurst M.K., Suuronen P. & Hulm A. (2006) Estimating collateral mortality from towed fishing gear. *Fish and Fisheries*, 7, 180–218.

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Appendix 1. Conservation actions not included in this synopsis

The table below is a list of the additional interventions with the potential to conserve marine fish that we identified but were not able to include in this synopsis. We searched a prioritized selection of journals (and years) specific to the marine environment (to add to those already searched as part of the Conservation Evidence project). However, due to the large volume of resulting studies, we were unable to summarize all of them in the time available. Therefore, to ensure we sufficiently covered at least one of the threat categories in full, and in partnership with the advisory board, we focussed our efforts on the conservation actions relating to '*Biological Resource Use'*. Here we found the bulk of the evidence, and it was deemed likely to be the most useful to fisheries managers and stakeholders in the wild fish resource. Note: Evidence for the interventions listed under 'Catch, Effort and Capacity Reduction' has been compiled and is currently being summarised. This section will be updated as soon as that is completed.

For each threat category or other category of interventions listed below (in bold), the number in brackets denotes the approximate number of studies found during our searches and from the Conservation Evidence discipline-wide literature database, for all the actions underneath.

Note: The numbers in brackets are the numbers of studies found at the search stage of the process and thus do not include any studies that may have subsequently been excluded because they did not fulfil the inclusion criteria for summarizing.

Threat: Residential and Commercial development (0)
• Prohibit or limit artificial lighting
• Prohibit or limit underwater piling activity
• Prohibit or limit dredging activity
Threat: Aquaculture (11)
<u>Marine and freshwater aquaculture</u>
• Cease or prohibit aquaculture in an area
• Locate aquaculture systems in non-sensitive areas for fish
• Reduce use of low trophic level fish in pellet production
• Replace pesticides with live organisms (e.g. wrasse) to control parasites or problem species in marine aquaculture installations
• Use captive-bred fish only to control parasites in marine aquaculture installations
• Use native species instead of non-native species in marine aquaculture systems
• Use sterile individuals in aquaculture systems
• Source juveniles only from approved and accredited hatchery facilities
• Remove marine fish farms from vulnerable ecosystem areas
• Install biofilters beneath marine aquaculture installations

• Leave marine aquaculture installations empty for a period (fallow)
• Change timing of parasite control in marine aquaculture systems
Threat: Energy production and mining (17)
Oil and Gas Drilling
• Cease or prohibit oil and gas drilling in an area
• Cease or prohibit the deposit of drill cuttings on the seabed
• Remove non-toxic drill cuttings, deposited during operation, as part of decommissioning
• Limit the thickness of drill cuttings deposited on the seabed
• Remove drill cuttings so they are not exposed at the seabed
• Use subsea rock installations for offshore oil and gas developments that reflect the substrate naturally occurring in the area
• Bury pipelines instead of covering them with subsea rock installations
• Limit the amount of material used for stabilisation of seabed installations
• Use alternative systems to maintain the position of vessels instead of anchoring
• Leave pipelines and infrastructure in place following decommissioning to minimise disturbance
• Remove pipelines and infrastructure following decommissioning
Marine Mining and Quarrying
• Cease or prohibit marine mining and aggregate extraction in an area
• Cease or prohibit marine mining and aggregate extraction during sensitive periods for fish
• Cease or prohibit separation at sea of aggregate material into specific sizes during sensitive periods for fish
• Set limits for change in particle size during aggregate extraction
• Restore seabed habitat and features after cessation of marine mining and quarrying
• Implement buffer zones around sensitive areas for fish
Renewable energy
• Cease or prohibit renewable energy installations in an area
• Locate renewable energy installations in non-sensitive areas for fish
• Use subsea rock installations for offshore renewable energy developments that reflect the substrate naturally occurring in the area
• Limit amount of stabilisation material used for renewable energy developments
• Prohibit piling activity during sensitive periods for fish to minimise physical disturbance
• Prohibit piling activity in sensitive locations for fish to minimise physical disturbance
• Modify design of underwater turbines to lower mortality from fish collision
• Install device to deter fish from entering renewable energy developments
Coastal Power plants
• Modify design of cooling water intake structures
• Reduce capacity of cooling water intake structures in areas of high ecological value

• Install device to increase the removal rate of organisms pinned against screens
• Install fish deterrent, diversion or return systems
• Reduce impacts of coolant water discharges (e.g. maximum ambient temperature change)
Threat: Transportation and service corridors (0)
Utility and service lines
• Prevent utility and service line cable routings from going through sensitive areas for fish
• Prohibit cable laying during sensitive periods for fish
• Use ploughing to install cables rather than water-jetted trenching
• Use materials that encourage the accumulation of sediment to cover cables in soft sediment areas
• Leave utility and service lines in place after decommissioning
• Design and locate power transmission cables to minimise risk of electro-magnetic interference
• Use cable mattressing materials for utility and service lines that reflect the substrate naturally occurring in the area
Shipping lanes
• Divert shipping routes
• Cease or prohibit anchoring in an area
• Cease or prohibit anchoring in an area during sensitive periods for fish
• Reduce speed limits to reduce wake energy intensity and underwater disturbance
Threat: Human intrusions and disturbance (80)
Recreational Activities
• Limit, cease or prohibit access for recreational purposes
• Limit, cease or prohibit recreational diving
• Limit, cease or prohibit recreational fishing in an area
• Prohibit recreational fishing during sensitive periods for fish
• Implement catch-and-release policies or, 'prohibit the retention of fish in hook and line fisheries' (also commercial)
• Change hook type
• Limit, cease or prohibit recreational boating
• Limit, cease or prohibit recreational anchoring
• Set limits on the amount of recreational catch
• Provide moorings for temporary use at sensitive or high use sites
• Restrict access (area or season)
• Introduce licences for recreational fishing
• Implement regulations or guidelines to control tourist-fish interactions
• Limit the minimum size of capture for recreationally fished species
• Change handling and release methods (e.g. vent the swim bladder, reduce air exposure, cut the line)
• Use different bait to reduce the amount of unwanted catch

• Set limits on the numbers of rods/hooks per angler
• Limit or prohibit competition/tournament fishing in an area
• Use a different lure
Work and other activities
• Reduce number of vessel movements in an area to reduce physical disturbance
• Prohibit construction during sensitive periods for fish to reduce physical disturbance
• Prohibit construction in an area to reduce physical disturbance
• Require cessation of works at intervals to reduce barriers to fish movements
Threat: Natural System modifications (0)
• Manage the removal or diversion of water from the natural environment in coastal and transitional waters
Threat: Invasive and other problematic species and genes (4)
• Limit, cease or prohibit ballast water exchange in specific areas
• Treat ballast water before exchange to prevent the spread of invasive and other problematic species
• Modify the timing of ballasting to reduce the uptake of invasive and other problematic species
• Limit, cease or prohibit the sale and/or transportation of commercial non-native species
• Introduce competitive fishing programmes for invasive and other problematic species
• Encourage capture of problematic species for commercial purposes, harvesting for sport or commercial fisheries
• Increase enforcement and fine structure for release of aquarium species
• Reduce or eliminate organisms associated with transfer of live seafood
• Dispose of non-native live bait on land
• Offer incentives for the capture of invasive and other problematic species
• Use biocides or other chemicals to control invasive or other problematic species
• Remove or capture invasive and other problematic species
• Use biological control to manage invasive and other problematic species
• Establish programs for the early detection of invasive and other problematic species
• Physically remove problematic species
• Implement regular inspections of aquaculture systems to avoid accidental introduction of invasive or problem species
• Control or eradicate aquaculture escapees
Threat: Pollution (13)
Domestic/urban wastewater
• Limit, cease or prohibit the dumping of untreated sewage
• Limit, cease or prohibit the dumping of sewage sludge
• Set or improve minimum sewage treatment standards

• Carry out secondary and tertiary treatment of sewage
• Limit the amount of storm wastewater overflow
• Treat stormwater
• Transplant/translocate bioremediating species
Industrial/military effluents
• Limit, cease or prohibit discharge of waste effluents overboard from vessels
• Regulate temperature of water discharged from power stations
• Prohibit discharge of waste overboard from vessels
• Use double hulls to prevent oil spills
• Establish pollution emergency plans
• Use booms and skimmers to remove oil pollution
• Use organisms to remove or neutralise pollutants
• Use an appropriate dispersant following an oil spill
• Add chemicals or minerals to sediment to remove or neutralise pollutants
• Introduce the requirement to pay compensation for ecosystem damage
• Introduce mechanisms to reimburse for environmental protection
• Prevent use of harmful chemicals
• Regulatory ban on marine burial of nuclear waste
• Carry out secondary and tertiary treatment of industrial waste
• Limit, cease or prohibit discharge of waste effluents from land
Agricultural/forestry effluents
• Regulate use and dosage of agrichemicals
• Treat wastewater from intensive livestock holdings
• Transplant/translocate bioremediating species
• Establish aquaculture facilities (e.g. seaweed) to extract the nutrients from run-off
• Establish artificial wetlands to help reduce effluent reaching the sea
• Manage land use to minimise run-off
• Carry out secondary and tertiary treatment of agricultural waste
• Use onshore pumped water aquaculture systems to control wastes
• Replace plastic feed pipes in salmon farming with non-polluting materials to reduce micro-plastic emissions into the marine environment
• Reduce feed waste and other waste produced in marine aquaculture
• Reduce the amount of pesticides used in marine aquaculture systems
• Reduce the amount of antibiotics used in marine aquaculture systems
• Use organisms to remove or neutralise contaminants within marine aquaculture systems
• Move aquaculture gear regularly to avoid waste build up on the seabed
• Cultivate shellfish near finfish aquaculture systems to improve water quality and minimise disease outbreaks
• Use systems to improve seawater conditions
Garbage and solid waste
• Prohibit waste dumping at-sea
• Install stormwater traps

• Use biodegradable package bands
• Promote litter reduction to reduce marine debris
• Remove litter from the marine environment
• Use biodegradable materials to construct fishing gear
• Recover lost fishing gear
• Use fishing surveys to recover lost fishing gear opportunistically
• Use scuba divers to recover lost fishing gear
• Offer rewards for finding and returning lost gear
• Improve seabed mapping and spatial information to reduce gear snagging and loss
• Attach transponders to fishing gear to locate if lost
• Use satellite detection of gears and traps
• Establish means of reporting lost gear
• Issue fines for late return (i.e. after close of season) of gear leased from government
• Register gear
<u>Excess energy</u>
• Use alternative methods instead of airguns for seismic testing
• Reduce demand for shipping (noise)
• Employ soft-start piling methods
• Prohibit piling during sensitive periods for fish
• Reduce hammer energy during piling
• Use methods to dampen underwater noise emissions (e.g. bubble curtains, hydro-sound dampeners)
• Prohibit piling activity during sensitive periods and in sensitive locations for fish
• Reduce use of civilian sonars
• Reduce seismic noise pollution (soft starts, improve directionality of airgun)
• Prohibit piling during sensitive periods for fish
• Reduce speed limits to reduce wake energy intensity and underwater noise
• Switch off industrial lighting at night
• Bury electricity cables to reduce electromagnetic effects
• Prohibit piling during sensitive periods for fish
• Prohibit underwater disturbance during sensitive periods for fish
• Prohibit underwater disturbance in an area
• Require periods of cessation of works
Threat: Climate change and severe weather (1)
• Restore species or habitats following extreme events
• Translocate species to manage range extensions
• Transplant climate change resistant species
• Develop climate resistant strains of sensitive species
Habitat protection (0: related evidence for those actions marked with an asterisk * is summarized under “Biological Resource Use” in the main synopsis)

• Designate a Particularly Sensitive Sea Area (PSSA) to regulate impactful maritime activities
• Designate a Marine Protected Area and prohibit all types of fishing*
• Designate a Marine Protected Area and prohibit commercial fishing*
• Designate a Marine Protected Area and prohibit bottom trawling*
• Designate a Marine Protected Area and install physical barriers to prevent trawling
• Designate a Marine Protected Area and prohibit dredging*
• Designate a Marine Protected Area and prohibit all towed (mobile) fishing gear*
• Designate a Marine Protected Area with a zonation system of activity restrictions*
• Designate a Marine Protected Area and prohibit static fishing gear*
• Designate a Marine Protected Area and only allow hook and line fishing
• Designate a Marine Protected Area and limit the number of fishing vessels
• Designate a Marine Protected Area and set a no-anchoring zone
• Designate a Marine Protected Area and allow the harvest of selected fish species only
• Designate a Marine Protected Area and prohibit the harvest of invertebrate species
• Designate a Marine Protected Area and introduce some fishing restrictions (types unspecified)*
• Designate a Marine Protected Area without setting management measures, access or usage restrictions or enforcement
Habitat restoration and creation (108)
• Create new habitat
• Provide artificial spawning habitat
• Restore degraded habitat
• Re-create lost habitat
Species Management (57)
Species recovery
• Provide refugia
• Provide supplementary food
• Translocate fish
Captive breeding, rearing and releases (ex-situ conservation)
• Captively breed or rear fish
• Release captive-bred fish
• Change or modify breeding or release methods to increase survivorship of released captive-bred fish (e.g. size at release, acclimatisation, choice of release site, detection of disease in wild populations)
• Choose genetic strains of fish bred in captivity for release that will not adversely affect wild populations
Education and Awareness (7)
• Promote seafood certification (e.g. ecolabels) to reduce consumer demand for certain species

• Organise boycotts to reduce demand for certain species
• Distribute seafood guides (what to eat, where to eat) to reduce consumer demand for certain species
• Educate the public to reduce consumer demand for certain species
• Promote alternatives to fishmeal such as vegetable, soy or insect to reduce demand for marine fish
• Educate fishers to minimise transfer of non-native or invasive species

Appendix 2: Literature searched for the Marine Fish Synopsis

A total of 269 journals were searched:

a) Journals directly relevant (28):

† signifies that the authors of this synopsis undertook parts or all of the systematic searches for the journal.

JOURNAL	Volume/Year searched
African Journal of Marine Science	Vol. 1 (1983) - Vol. 39 (2017)
Aquatic Conservation: Marine and Freshwater Ecosystems	Vol. 1 (1991) - Vol. 27 (2017)
Aquatic Ecology (Springer)	Vol. 2 Issue 2 (1968) - Vol. 50 Issue 4 (2016)
Aquatic Ecosystem Health & Management	Vol. 1 Issue 1 (1998) - Vol. 19 Issue 4 (2016)
Aquatic Invasions	Vol. 1 (2006) - Vol. 11 (2016)
Aquatic Living Resources (Ressources Vivantes Aquatiques)	Vol. 1 Issue 1 (1988) - Vol. 29 Issue 4 (2016)
Canadian Journal of Fisheries and Aquatic Sciences	Vol. 1 (1901) - Vol. 69 (2012)
Estuarine, Coastal and Shelf Science	Keyword search 2000 - 2017
Fisheries†	Vol. 42. Issue 1 (2017) – Vol. 43 Issue 12 (2018)
Fish and Fisheries†	Vol. 1 Issue 1 (2000) - Vol. 19 Issue 6 (2018)
Fisheries Management and Ecology†	Vol. 1 Issue 1 (1994) - Vol. 25 Issue 6 (2018)
Fisheries Research†	Vol. 8 Issue 3 (1990) – Vol. 208 (2018)
Fisheries Oceanography†	Vol. 1 Issue 1 (1992) – Vol. 27 Issue 6 (2018)
Hydrobiologia	1995 - 2017
ICES Journal of Marine Science†	Vol. 46 Issue 2 (1990) Vol. 75 Issue 6 (2018)
Journal of Coastal Research†	2015 - 2018
Journal of Sea Research (formerly Netherlands Journal of Sea Research)	Vol. 1 (1961) - Vol. 129 (2017)
Journal of the Marine Biological Association of the United Kingdom	Vol. 1 Issue 1 (1887) - Vol. 86 Issue 6 (2006) + keyword search 2000 - 2017
Journal of Wetlands Ecology	Vol. 1 (2008) - Vol. 6 (2012)
Journal of Wetlands Environmental Management	Vol. 1 (2012) - Vol. 4 (2016)
Limnologica - Ecology and Management of Inland Waters	Vol. 29 (1999) - Vol. 65 (2017)
Mangroves and Saltmarshes (Springer)	Vol. 1 (1996) – Vol. 3 (1999)
Marine Ecological Progress Series	Keyword search 2010 - 2017
Marine Environmental Research	Vol. 1 (1978) - Vol. 131 (2017)

Marine Pollution Bulletin	Vol. 60 (2010) - Vol. 124 (2017)
Regional Studies in Marine Science	Vol. 1 (2015) - Vol. 15 (2017)
Wetlands	1981 - 2016
Wetlands Ecology and Management	Vol. 1 (1989) - Vol. 24 (2016)

b) All other journals searched as part of CE (241):

* signifies that the journal is of wider relevance to this synopsis.

JOURNAL	Volume/Year searched
Acta Chiropterologica	Vol. 1 (1999) - Vol. 19 (2017)
Acta Herpetologica	Vol. 1 (2006) - Vol. 7 (2012)
*Acta Oecologica-International Journal of Ecology**	Vol. 11 Issue 1 (1990) - Vol. 84 (2017)
Acta Theriologica Sinica	Vol. 20 Issue 1 (2000) - Vol. 37 Issue 4 (2017)
African Bird Club Bulletin	2010-2016
African Journal of Ecology	Vol. 1 Issue 1 (1963) - Vol. 54 Issue 4 (2016)
African Journal of Herpetology (formerly The Journal of the Herpetological Association of Africa)	Vol. 38 (1990) - Vol. 61 Issue 1 (2012)
African Primates	1995 - 2012
African Zoology	Vol. 1 (1979) - Vol. 48 (2013)
Agriculture, Ecosystems and Environment	Vol. 10 Issue 3 (1983) - Vol. 250 (2017)
Agroforestry Systems (Springer)	Vol. 1 (1982) - Vol. 71 (2007)
*Ambio**	Vol. 1 Issue 1 (1972) - Vol. 40 Issue 1 (2011)
American Journal of Primatology	1981-2014
American Naturalist	Vol. 1 Issue 1 (1867) - Vol. 190 (2017)
Amphibian and Reptile Conservation	Vol. 1 (1996) - Vol. 9 (2016)
Amphibia-Reptilia	Vol. 1 (1980) - Vol. 37 (2016)
*Animal Biology**	Vol. 53 Issue 1 (2003) - Vol. 63 Issue 3 (2013)
*Animal Conservation**	Vol. 1 (1998) - Vol 21 Issue 1 (2018)
Animal Welfare	Vol. 1 (1992) - Vol. 25 (2016)
Annales Zoologici Fennici	Vol. 1 (1964) - Vol. 50 Issue 4 (2013)
Annales Zoologici Societatis Zoologicae Botanicae Fennicae Vanamo	Vol. 1 (1932) - Vol. 25 (1963)
*Annual Review of Ecology, Evolution, and Systematics (formerly Annual Review of Ecology and Systematics)**	Vol. 1 (1970) - Vol. 48 (2017)
Anthrozoos	Vol. 1 (1987) - Vol. 26 (2013)
Apidologie	Vol. 1 (1958) - Vol. 40 (2009)
*Applied Animal Behaviour Science**	Vol. 12 Issue 1 (1988) - Vol. 151 (2014)

Applied Herpetology	Vol. 1 (2003) - Vol. 6 (2009)
Applied Vegetation Science	Vol. 1 Issue 1 (1998) - Vol. 20 Issue 4 (2017)
Aquatic Botany	Vol. 1 (1975) - Vol. 137 (2017)
Aquatic Mammals	Vol. 1 (1972) - Vol. 43 (2017)
Arid Land Research and Management (formerly Arid Soil Research and Rehabilitation)	Vol. 1 Issue 1 (1987) - Vol. 27 Issue 4 (2013)
Asian Primates	2008- 2012
Asiatic Herpetological Research	Vol. 5 (1993) - Vol. 11 (2008)
Auk	(1980 - 2016)
Austral Ecology	Vol. 1 (1977) - Vol. 42 (2017)
Australasian Journal of Herpetology	Vol. 1 (2009) - Vol. 15 (2012)
Australasian Plant Conservation	Vol. 1 Issue 1 (1991) - Vol. 19 Issue 2 (2010)
Australian Mammalogy	Vol. 22 Issue 1 (2000) - Vol. 39 Issue 2 (2017)
Avian Conservation and Ecology	Vol. 1 (2005) - Vol. 11 (2016)
*Basic and Applied Ecology**	Vol. 1 Issue 2 (2000) - Vol. 25 (2017)
*Behavioral Ecology**	Vol. 1 Issue1 (1990) - Vol. 24 Issue 4 (2013)
Behaviour	Vol. 1 Issue 1 (1948)- (2013)
Bibliotheca Herpetologica	1999 - 2012
Biocontrol (formerly Entomophaga)	Vol. 1 Issue 1 (1956) - Vol. 61 Issue 6 (2016)
Biocontrol Science and Technology	Vol.1 issue 1 (1991) - Vol. 6 issue 2 (1996)
*Biodiversity and Conservation**	Vol. 3 Issue 1 (1994) - Vol. 26 Issue 14 (2017)
*Biological Conservation (Elsevier)**	Vol. 21 (1981) - Vol. 216 (2017)
*Biological Control**	Vol. 1 issue 1 (1991) - Vol. 107 (2017)
*Biological Invasions (Springer)**	Vol. 1 (1999) - Vol. 19 Issue 6 (2017)
*Biology and Environment**	Vol. 93 (1993) - Vol. 117 (2017)
*Biology Letters**	Vol. 1 Issue 1 (2005) - Vol. 9 Issue 12 (2017)
Biotropica	Vol. 1 (1990) - Vol. 49 (2017)
Bird Conservation International	1991 - 2016
Bird Study	1980 - 2016
Boreal Environment Research	Vol. 1 Issue 1 (1996) - Vol. 19 Issue 1 (2014)
Bulletin of the Herpetological Society of Japan	1999 - 2008
Canadian Field-Naturalist (formerly Ottawa Naturalist)	Vol. 1 Issue 1 (1987) - Vol. 131 Issue 4 (2017)
Canadian Journal of Forest Research	Vol. 1 (1971) - Vol. 43 (2013)
Caribbean Journal of Science	Vol.1 (1961)-Vol.46 Issue 2-3(2013)
Chelonian Conservation and Biology	Vol. 5 (2006) - Vol. 12 (2013)
Collinsorum (formerly Journal of Kansas Herpetology)	2002 - 2014
*Community Ecology**	Vol. 1 (2000) - Vol. 13 (2012)
*Conservation Biology**	Vol. 1 (1987) - Vol. 31 Issue 6 (2017)
*Conservation Evidence**	Vol. 1 (2004) - Vol. 15 (2018)

*Conservation Genetics**	Vol. 1 Issue 1 (2000) - Vol. 14 Issue 4 (2013)
*Conservation Letters**	Vol. 1 Issue 1 (2008) - Vol. 10 Issue 6 (2017)
Contemporary Herpetology	1998 - 2009
Contributions to Primatology	1974 - 1991
Copeia	1910 - 2003 & Vol. 1 (2000) - Vol. 17 (2016)
Cunninghamia	Vol. 1 (1981) - Vol. 16 (2016)
Current Herpetology (formerly Acta Herpetologica Japonica, and Japanese Journal of Herpetology)	Vol. 1 (1964) - Vol. 31 (2012)
Dodo	Vol. 14 (1977) - Vol. 37 (2001)
Ecological and Environmental Anthropology	2005 - 2008
*Ecological Applications**	Vol. 1 Issue 1 (1991) - Vol. 27 Issue 8 (2017)
*Ecological Indicators**	2001 - 2007
*Ecological Management and Restoration**	Vol. 1 (2000) - Vol. 18 (2017)
*Ecological Restoration**	Vol. 1 (1981) - Vol. 35 Issue 4 (2017)
*Ecology**	Vol. 17 Issue 1 (1936) - Vol. 97 Issue 12 (2017)
*Ecology Letters**	Vol. 1 Issue 1 (1998) - Vol. 16 issue 9 (2013)
Écoscience	Vol. 1 Issue1 (1994) - Vol. 20 Issue 2 (2013)
*Ecosystems**	Vol. 1 Issue1 (1998) - Vol. 16 Issue 8 (2013)
Emu	1980 - 2016
*Endangered Species Research**	Vol. 1 (2004) - Vol. 34 (2017)
*Environmental Conservation**	Vol. 1 Issue 1 (1974) - Vol. 44 Issue 4 (2017)
*Environmental Evidence**	Vol. 1 (2012) - Vol. 6 (2017)
*Environmental Management**	Vol. 1 (1977) - Vol. 60 Issue 6 (2017)
Environmentalist	Vol. 1 Issue 1 (1981) - Vol. 8 Issue 1 (1988)
Ethology Ecology & Evolution	Vol. 1 Issue 1 (1989) - Vol. 26 Issue 1 (2014)
European Journal of Soil Science	Vol. 1 (1950) - Vol. 63 (2012)
European Journal of Wildlife Research (Springer) (formerly Zeitschrift für Jagdwissenschaft)	Vol. 1 (1955) - Vol. 63 Issue 6 (2017)
Evolutionary Anthropology	1992 - 2014
*Evolutionary Ecology**	Vol. 1 Issue1 (1987) - Vol. 28 Issue 1 (2014)
*Evolutionary Ecology Research**	Vol. 1 Issue1 (1999) - Vol. 15 Issue 6 (2014)
Fire Ecology	Vol. 1 Issue 1 (2005) - Vol. 12 Issue 1 (2016)
Folia Primatologica	1963 - 2014
Folia zoologica	Vol. 4 (1959) - Vol. 62 (2013)
Forest Ecology and Management	Vol. 1 (1976) - Vol. 294 (2013)
Freshwater Biology	1975 - 2017
Freshwater Science (formerly Freshwater Invertebrate Biology 1982-1985; and Journal of the North American Benthological Society)	Vol. 1 issue 1 (1982) - Vol. 36 Issue 3 (2017)
*Functional Ecology**	Vol. 1 Issue 1 (1987) - Vol. 27 Issue 3 (2013)
Genetics and Molecular Research	Vol. 1 Issue 1 (2002) - Vol. 12 Issue 2 (2013)

Geoderma	Vol. 1 (1967) - Vol. 180 (2012)
Gibbon Journal	2005 - 2011
*Global Change Biology**	Vol. 1 Issue 1 (1995) - Vol. 23 Issue 12 (2017)
*Global Ecology and Biogeography**	Vol. 1 Issue 6 (1991) - Vol. 23 Issue 2 (2014)
Grass and Forage Science	Vol. 35 Issue 1 (1980) - Vol. 72 Issue 4 (2017)
Herpetofauna	2003 - 2007
Herpetologica	Vol. 1 (1936) - Vol. 68 (2012)
Herpetological Conservation and Biology	Vol. 1 (2006) - Vol. 7 (2012)
Herpetological Journal	Vol. 1 (1985) - Vol. 22 (2002)
Herpetological Monographs	Vol. 1 (1982) - Vol. 26 (2012)
Herpetological Review	1967 - 2014
Herpetology Notes	2008 - 2014
*Human Wildlife Interactions (formerly Human Wildlife Conflicts)**	Vol. 1, Issue 1 (2007) - Vol. 11 Issue 3 (2017)
Hystrix, the Italian Journal of Mammalogy	Vol. 1 Issue1 (1986) - Vol. 28 Issue 2 (2017)
Ibis	1980 - 2016
iForests	Vol. 1 (2008) - Vol. 9 (2016)
*Integrative Zoology**	Vol. 1 Issue 1 (2006) - Vol. 8 Issue 2 (2013)
International Journal of Pest Management (formerly PANS Pest Articles & News Summaries, PANS, and Tropical Pest)	Vol. 1 (1969) - Vol. 25 (1979)
International Journal of Primatology (Springer)	1980 - 2012
International Journal of the Commons	Vol. 1 Issue 1 (2007) - Vol. 10 Issue 2 (2016)
International Journal of Wildland Fire	Vol. 1 Issue 1 (1991) - Vol. 25 Issue 11 (2016)
International Wader Studies	1970 – 1972
International Zoo Yearbook	Vol. 1 (1960) - Vol. 49 (2015)
Invasive Plant Science and Management	Vol. 1 (2008) - Vol. 9 (2016)
Israel Journal of Ecology & Evolution	Vol. 12 Issue 1 (1963) - Vol. 59 Issue 2 (2013)
Italian Journal of Zoology	Vol. 45 Issue 1 (1978) - Vol. 80 Issue 4 (2013)
*Journal for Nature Conservation**	Vol. 10 (2002) - Vol. 40 (2017)
*Journal of Animal Ecology (BES)**	Vol. 1 (1932) - Vol. 86, Issue (2017)
Journal of Apicultural Research	Vol. 1 (1962) - Vol. 48 (2009)
*Journal of Applied Ecology**	Vol. 1, Issue 1 (1964) - Vol. 54 Issue 6 (2017)
Journal of Aquatic Plant Management (formerly Hyacinth Control Journal)	Vol. 1 (1962) - Vol. 54 (2016)
Journal of Arid Environments	Vol. 24 (1993) - Vol. 136 (2017)
Journal of Avian Biology (formerly Ornis Scandinavica)	1980 - 2016
Journal of Cetacean Research and Management	Vol. 1 (1999) - Vol. 12 (2012)
*Journal of Ecology**	Vol. 21 Issue 1 (1933) - Vol. 105 Issue 6 (2017)
*Journal of Environmental Management**	Vol. 1 (1973) - Vol. 204 (2017)

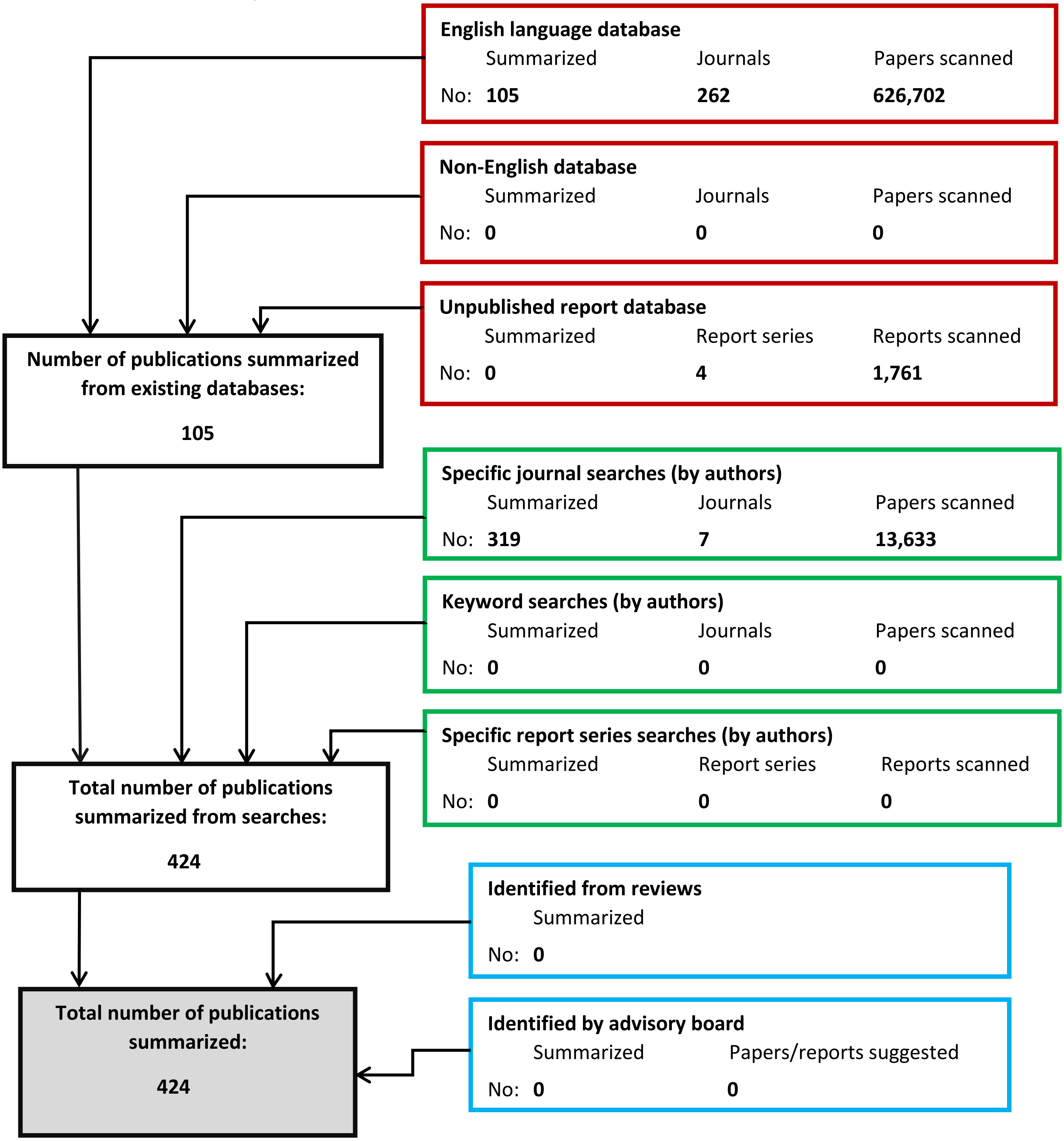
Journal of Field Ornithology	1980 - 2016
Journal of Forest Research	Vol. 1 Issue 1 (1996) - Vol. 22 Issue 1 (2017)
Journal of Great Lakes Research	Vol. 1 (1975) – Vol. 43 (2017)
Journal of Herpetological Medicine and Surgery	2009 - 2013
Journal of Herpetology	1968 - 2015
Journal of Insect Conservation	Vol. 1 (1997) - Vol. 13 (2009)
Journal of Mammalian Evolution	Vol. 1 Issue 1 (1993) - Vol. 21 Issue 1 (2014)
Journal of Mammalogy	Vol. 1 (1919) - Vol. 98 (2017)
Journal of Mountain Science	Vol. 1 Issue 1 (2004) - Vol. 13 Issue 8 (2016)
Journal of Negative Results: Ecology and Evolutionary Biology	Vol. 1 (2004) - Vol. 11 (2016)
Journal of Ornithology	Vol. 145 Issue 1 (2004) - Vol. 159 Issue 1 (2018)
Journal of Primatology	2012 - 2013
Journal of Raptor Research	1966 - 2016
Journal of Tropical Ecology	Vol. 2 (1986) - Vol. 33 (2017)
Journal of Vegetation Science	Vol. 1 Issue 1 (1990) – Vol. 28 Issue 3 (2017)
Journal of Wildlife Diseases	Vol. 1 (1965) - Vol. 48 (2012)
Journal of Wildlife Management	Vol. 9 Issue 4 (1945) - Vol. 81 Issue 8 (2017)
Journal of Zoo & Aquarium Research	Vol. 1 (2013) - Vol. 4 (2016)
*Journal of Zoology**	Vol. 149 (1966) - Vol. 303 Issue 4 (2017)
Jurnal Primatologi Indonesia	2009
Kansas Herpetological Society Newsletter	1977, 1983, 1998, 2001
Lake and Reservoir Management	Vol. 1 Issue 1 (1984) - Vol. 32 Issue 4 (2016)
Land Degradation and Development	Vol. 1 Issue 1 (1989) - Vol. 27 Issue 8 (2016)
Land Use Policy	Vol. 1 (1984) - Vol. 29 (2012)
Latin American Journal of Aquatic Mammals	Vol. 1 (2002) - Vol. 11 (2016)
Lemur News	1993 - 2012
Mammal Research (formerly Acta Theriologica)	Vol. 1 (1977) - Vol. 62 (2017)
Mammal Review	Vol. 1 (1970) - Vol. 47 (2017)
Mammal Study	Vol. 30 Issue 1 (2005) - Vol. 42 Issue 4 (2017)
Mammalia	Vol. 1 (1937) - Vol. 31 (2017)
Mammalian Biology	Vol. 67 Issue 1 (2002) - Vol. 87 (2017)
Mammalian Genome	Vol. 1 Issue 1 (1991) - Vol. 24 Issue 8 (2013)
*Management of Biological Invasions**	Vol. 1 (2010) - Vol. 7 (2016)
Marine Mammal Science	Vol. 1 (1985) - Vol. 13 (2017)
Mires and Peat	Vol. 1 (2006) - Vol. 18 (2016)
Natural Areas Journal	Vol. 12 Issue 3 (1992) - Vol. 37 Issue 2 (2017)
NeoBiota	Vol. 9 (2011) - Vol. 34 (2017)
Neotropical Entomology	Vol. 30 (2001) – Vol. 36 (2007)
Neotropical Primates	1993 - 2014

New Journal of Botany	Vol 1, Number 1 (June 2011) - Feb 2013
New Zealand Journal of Zoology	Vol. 1 Issue 1 (1974) - Vol. 44, Issue 4 (2017)
New Zealand Plant Protection	Vol. 53 (2000) – Vol. 69 (2016)
Northwest Science	Vol. 81 Issue 1 (2007) - Vol. 90 Issue 3 (2016)
*Oecologia**	Vol. 3 Issue 3 (1969) - Vol. 185 Issue 4 (2017)
*Oikos**	Vol. 1 Issue 1 (1949) - Vol. 126 Issue 12 (2017)
Ornitologia Neotropical	Vol. 1 (1990) - Vol. 29 (2018)
*Oryx**	Vol. 1 (1950) - Vol. 51 Issue 4 (2017)
Ostrich	1980 - 2016
Pacific Conservation Biology	Vol. 1 Issue 1 (1993) - Vol. 23 Issue 4 (2017)
Pakistan Journal of zoology	Vol. 36 Issue 1 (2004) - Vol. 45 Issue 3 (2013)
Phyllomedusa	Vol. 1 (2002) - Vol. 11 (2012)
Plant Ecology (formerly Journal of Plant Ecology)	Vol. 1 (1948) - Vol. 193 (2007)
Plant Ecology & Diversity (formerly Transactions of the Botanical Society of Edinburgh)	Vol. 1 (2008) - Vol. 5 (2013)
Plant Protection Quarterly	Vol. 23 (2008) – Vol. 31 (2016)
*PLOS**	Vol. 1 (2006) - Vol. 8 (2013)
Polish Journal of Ecology	Vol. 50 Issue 2 (2002) - Vol. 61 Issue 2 (2013)
*Population Ecology**	Vol. 1 Issue 1 (1952) - Vol. 55 Issue 4 (2013)
Preslia	Vol. 45 Issue 1 (1973) - Vol. 89 Issue 4 (2017)
Primate Conservation	1981 - 2014
Primates	Vol. 1 Issue 1 (1957) - Vol. 54 Issue 4 (2013)
Rangeland Ecology & Management (formerly Journal of Range Management)	Vol.1 (1948) - Vol. 69 (2016)
Raptors Conservation	2005 - 2016
*Restoration Ecology**	Vol. 1 (1993) - Vol. 25 (2017)
Revista Chilena de Historia Natural (RCHN)	Vol. 73 (2000) - Vol. 89 (2016)
Revista de Biologia Tropical	Vol. 24 Issue 2 (1976) - Vol. 35 Issue 3 (2013)
River Research and Applications	1987 - 2016
Russian Journal of Ecology	1993 - 2017
Russian Journal of Herpetology	1994 - 2000
Salamandra	Vol. 26 (2000) - Vol. 52 (2016)
Slovak Raptor Journal	2007 - 2016
Small Ruminant Research	Vol. 1 (1988) - Vol. 156 (2017)
Soil Biology and Biochemistry	1969 - 2012
Soil Use and Management	1985 - 2012
South African Journal of Botany	Vol. 1 (1982) - Vol. 108 (2016)
South African Journal of Wildlife Research	Vol. 1 Issue 1 (1971) - Vol. 144 (2014)
South American Journal of Herpetology	Vol. 1 (2006) - Vol. 7 (2012)
Southern Forests	Vol. 70 Issue 1 (2008) - Vol. 75 Issue 4 (2013)

*Systematic Reviews Centre for Evidence-Based Conservation**	All reviews published up to December 2017
The Condor	1980 - 2016
The Rangeland Journal	Vol 1, Issue 1 (1976) - Vol. 38 Issue 5 (2016)
The Southwestern Naturalist	Vol. 1 Issue 1 (1956) - Vol. 58 Issue 2 (2013)
The Wilson Journal of Ornithology (formerly The Wilson Bulletin)	1980 - 2016
*Trends in Ecology and Evolution**	Vol. 1 Issue 1 (1986) - Vol. 32 Issue 12 (2017)
Tropical Conservation Science	Vol. 1 Issue 1 (2008) - Vol. 7 Issue 1 (2014)
Tropical Ecology	Vol. 1 Issue 1 (1960) - Vol. 55 issue 1 (2014)
Tropical Grasslands	Vol. 1 (1967) - Vol. 44 (2010)
Tropical Zoology	Vol. 1 Issue1 (1988) - Vol. 26 Issue 4 (2013)
Turkish Journal of Zoology	Vol. 20 Issue 1 (1996) - Vol. 38 Issue 2 (2014)
Vietnamese Journal of Primatology	2007 - 2009
Waterbirds (formerly Colonial Waterbirds; and Proceedings of the Colonial Waterbird Group)	1983 - 2016
Weed Biology and Management	Vol. 1 Issue 1 (2001) - Vol. 16 Issue 4 (2016)
Weed Research	Vol. 1 (1961) - Vol. 57 (2017)
West African Journal of Applied Ecology	Vol. 1 (2000) - Vol. 24 (2016)
Western North American Naturalist	Vol. 60 Issue 2 (2000) - Vol. 72 Issue 2 (2016)
Wildfowl	Vol. 1 (1948) - Vol. 66 (2016)
Wildlife Biology	Vol. 1 (1995) - Vol. 19 (2013)
Wildlife Monographs	Vol. 1 (1958) - Vol. 183 (2013)
Wildlife Research (formerly CSIRO Wildlife Research; and Australian Wildlife Research)	Vol. 1 (1956) - Vol. 43 (2016)
Wildlife Society Bulletin	Vol. 1 (1973) - Vol. 41 (2017)
Zhurnal Obshchei Biologii	Vol. 33 Issue 1 (1972) - Vol. 74 Issue 6 (2013)
Zoo Biology	Vol. 1 Issue 1 (1982) - Vol. 35 Issue 2 (2016)
Zookeys	Vol. 1 (2008) - Vol. 312 (2013)
Zoologica Scripta	Vol. 1 Issue 1 (1971) - Vol. 43 Issue 1 (2014)
Zoological Journal of the Linnean Society	Vol. 1 Issue 1 (1856) - Vol. 169 Issue 4 (2013)
Zootaxa	2004 - 2014

Appendix 3. Literature reviewed for the Marine Fish Synopsis

The diagram below shows the number of journals searched for this synopsis, the total number of publications scanned (at title and abstract) within those, and the number of publications that were summarized from each source of literature. In red boxes are the references obtained from the Conservation Evidence database during all the authors searches. In green boxes are the searches undertaken by the authors of this synopsis. In blue boxes are the studies obtained from systematic reviews and as direct suggestions from the Advisory Board.



Appendix 4. Glossary of terms

Bycatch: The use of this term in the literature has more than one meaning depending on the study and for this reason we have typically refrained from using it in this synopsis. Its primary use is to describe fish that are harvested in a fishery but not kept for sale or personal use (i.e. all fish, commercially targeted or otherwise, that are returned to the sea because they have no economic value or it is mandatory to do so). However, it is also used to describe catch that was not part of the main species/fishery being targeted but nevertheless has economic value and so is retained for sale. For example, marketable fish caught as part of commercial target fisheries for shrimp/prawn species may be termed as "fish bycatch", even though they are retained for sale.

Bycatch reduction device: Commonly referred to in the literature as BRDs. A general name used in fisheries to refer to a suite of net modifications and/or devices used on trawl nets to increase selectivity and reduce the amount of accidental unwanted catch by allowing them to 'escape' (for instance through holes, escape zones, or sections of the trawl net with bigger or different mesh geometry). BRDs tend to let species and organisms escape that are smaller than those targeted by the fishery.

Codend: The narrow end part of a fishing trawl net where the catch is retained.

Commercial catch: During fishing, this is the portion of the catch that is retained and has some economic value. It includes the species directly targeted by the fishery as well as other species of commercial value that are accidentally caught.

Crustacean: Any members of the subphylum Crustacea within the phylum Arthropoda. In majority marine, they include (but are not limited to): crabs, lobsters, prawns/shrimps, amphipods, barnacles, etc.

Demersal/groundfish: Used to describe both the fish living on or close to the floor of the sea or estuary and the fishing gears that are deployed on or close to the bottom to catch them (contrasts with pelagic).

Discard: During fishing, this is the portion of the unwanted catch that is not retained and returned to the sea.

Fishing gear selectivity: The measurement of the selection process of a fishing gear. It is a comparison of the length and frequency of each species caught to that of the total population available to catch.

Pelagic: Used to describe both the fish that mainly inhabit the upper layers of the water column in open seas and the fishing gears that are deployed in mid-water or near the surface to catch them (contrasts with demersal).

Shellfish: A commonly used term for commercially important species of aquatic organisms that have a shell or exoskeleton. They include (but are not limited to):

molluscs such as oysters, mussels, abalone, winkles; crustaceans such as crabs, lobsters, prawns/shrimps; and echinoderms such as sea urchins.

Sievenet: A cone-shaped net (funnel-like device) inserted into standard fishing trawl nets, which directs unwanted catch to an escape hole in the body of the trawl. The idea is that the target species go over the hole in the net, while non-target can escape through the release hole. This 'bycatch reduction device' is based on the separator panel principle. It is not made of rigid material and therefore it is more acceptable to fishers than a rigid sorting grid.

Turtle excluder device: Commonly referred to in the literature as TEDs. A general name used in fisheries to refer to a suite of modifications and/or devices used on trawl nets to increase selectivity and reduce the amount of accidental unwanted catch by preventing organisms from entering the net and/or codend (for instance by fitting a sorting grid at the entrance of the codend). TEDs tend to prevent the entry of species and organisms larger than those targeted by the fishery. Originally developed to reduce the accidental catch of turtles, they are now widely used to prevent the catch of many large marine species.

Unwanted catch: During fishing, this is the portion of the catch caught in the net that is not directly being targeted by the fishery (this can be for commercial or non-commercial purposes). It includes unwanted non-commercial organisms ('discards'), and other 'bycatch' such as undersized individuals of the target species and commercial species which are not the main target of the fishery.